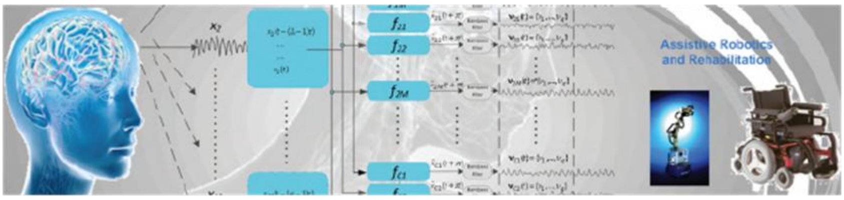
UKIERI Workshop

Fusion of Brain-Computer Interface and Assistive Robotics
7-8 July, 2011



UKIERI Standard Award Project (SA-07-0074): ***Innovations in Intelligent Assistive Robotics***

Brain-Computer Interface & Assistive Technology Team, Intelligent Systems Research Centre, School of Computing and Intelligent Systems, Faculty of Computing and Engineering, University of Ulster, Magee Campus, Londonderry, N Ireland, UK.

Preface

Over the last decade massive progress has been made in both brain-computer interface (BCI) and assistive robotics (AR) fields. A BCI primarily utilizes brainwaves modulations generated through voluntary cognitive tasks effected cortical activations. These modulations can be used to establish a direct communication link between human brain and computing devices and may also be effective in plastic reorganisation of neuronal structure after lesion formation due to neurological problems such as stroke. Several promising prototype BCI applications have been reported primarily for providing independence to people with extreme motor disability and helping in the recovery of paralysed limbs of individuals suffering from motor impairments due to stroke. However due to practical limitations, there is still very little take-up of BCI systems for real-world use.

In the AR field as well, highly promising prototype systems have been demonstrated for helping disabled individuals in mobility, performing activities of daily living (ADL), and undertaking rehabilitation exercises for the recovery of paralysed limbs. These systems include a range of devices involving smart wheelchair, tele-robotics, intelligent manipulators, and prosthetic and orthotic devices. AR systems also have yet to find wide-spread use in real-world. One of the main reasons for the limited take-up of AR systems is restrictive accessibility and passive interactions facilitated through the use of conventional human-computer interfaces.

A synergetic fusion of BCI and AR systems thus holds a much greater promise in ensuring active interactions and universal accessibility by establishing a natural communication link with AR systems through a user-centred design, leading to greater independence in ADL as well as enhanced recovery of the paralysed limbs. The UKIERI workshop is aimed at bringing together leading experts in both BCI and AR fields at one platform to discuss cutting edge developments and brainstorm ideas to provide new directions for an effective fusion of BCI and AR systems.

This workshop is organised under the UK India Education and Research Initiative (UKIERI) project (SA-07-0074): *Innovations in Intelligent Assistive Robotics,* wherein the Intelligent Systems Research Centre (ISRC) researchers at the University of Ulster (UU) have teamed up with scientists at the Indian Institute of Technology (IIT) Kanpur to investigate intelligent systems associated with developing brain-actuated assistive robotic systems for people with severe movement disabilities. The workshop includes eight keynote talks by invited speakers who are world-leading experts in at least one of the three areas BCI, AR, and their fusion. It also includes additional nine talks and sixteen poster presentations selected through a rigorous review process. Extended abstracts of all thirty three presentations are included in this workshop proceedings.

We gratefully acknowledge the funding support received through the UKIERI project (SA-07-0074) for organising this workshop. We are most grateful to invited speakers for taking time out of their busy schedules to come to N. Ireland and attend the workshop. We wish to sincerely thank the members of workshop committee for their time, effort, and expertise in reviewing the submissions. We would also like to express our sincere gratitude to Jhonatan Garcia, Peter Devine, Emma McLaughlin, Brenda Plummer, Martin Doherty, Gaurav Garg, Vaibhav Gandhi, Prem Kumar, and Karl McCreadie for their support in organising the event. Finally, we would like to thank our sponsors for their various kinds of support; Technical Committee on Brain-Machine Interface Systems, IEEE Systems, Man and Cybernetics Society, UKRI chapter of the IEEE Computational Intelligence Society (CIS), g.tec medical engineering GmbH, Austria, Brain Products GmbH and Brain Vision UK.

July 7, 2011 — Dr Girijesh Prasad

Derry/Londonderry

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Invited Talks and Speakers

- ***Advances in BCIs***

1. Possibilities for Human Enhancement through BCI
Prof. Kevin Warwick, Professor of Cybernetics, University of Reading, UK

2. Developing practical brain-computer interfaces: Opportunities and challenges
Dr Christoph Guger, g.tec medical engineering GmbH, Austria.

3. EEG-fNIRS fusion for Practical Brain Computer Interfaces
Dr Tomas Ward, National University of Ireland Maynooth, Ireland.

4. Hybrid brain-computer interfaces: current state and future directions
Dr. Gernot Müller-Putz, Laboratory of Brain-Computer Interfaces, Graz University of Technology, Austria.

- ***Advances in ARs***

5. Robotic Exoskeletons for Functional Training of the Motor Impaired
Prof. Dr. Sunil Kumar Agrawal, Department of Mechanical Engineering
University of Delaware, USA.

6. Cooperative Control of Multi-robot Systems for Societal Benefit
Prof. Debasish Ghose, Indian Institute of Science, Bangalore, India.

- ***Fusion of BCI and AR***

7. Partner Robots for Mental Health Care - Japanese Challenge toward Practical Robots
Prof. Goro Obinata, EcoTopia Science Institute Nagoya University, Japan.

8. Control of rehabilitation robot FRIEND by BCI: Experiences, new developments and future applications
Prof. Axel Gräser, Institut für Automatisierungstechnik, Universität Bremen, Germany.

Agenda

July 7, 2011

Time slot	Title
0830 – 0930	Registration and Coffee
0930 – 1200	Session-1 Chair: Professor Martin McGinnity Co-chair: Professor Bryan Scotney
0930 – 1000	**Workshop Opening**
1000 - 1040	**Developing practical brain-computer interfaces: Opportunities and challenges** Dr Christoph Guger, g.tec, Graz, Austria.
1040 – 1120	**Hybrid brain-computer interfaces: current state and future directions** Dr Gernot Müller-Putz, Institute for Knowledge Discovery, Graz University of Technology, Austria.
1120 – 1200	**EEG-fNIRS fusion for Practical Brain Computer Interfaces** Dr Tomas Ward, National University of Ireland Maynooth, Ireland.
1200 – 1320	**Lunch and poster viewing**
1320 – 1520	Session-2 Chair: Professor Goro Obinata Co-chair: Dr Gernot Müller-Putz
1320 – 1400	**Advancing Motor Imagery based BCI and its Applications** Dr Girijesh Prasad, ISRC, University of Ulster, Magee Campus, UK.
1400 – 1440	**Possibilities for Human Enhancement through BCI** Professor Kevin Warwick, University of Reading, UK.
1440 – 1500	**Hybrid BCI controlled FES for rehabilitation of the hand in acute tetraplegic patients** Dr Aleksandra Vuckovic, School of Engineering, University of Glasgow, UK
1500 – 1520	Coffee Break
1520 – 1700	Session-3 Chair: Professor Axel Gräser Co-chair: Professor Debasish Ghose
1520 – 1540	**A Low Cost Gaze- and Blink Based HCI** Dr Venkatesh K Subramanian, Indian Institute of Technology, Kanpur, India
1540 – 1600	**Towards natural hands-free human-robot interaction – methods and applications** Dr Hendrik Koesling, Research Institute for Cognition and Robotics (CoR-Lab), Bielefeld University, Germany.
1600 - 1620	**On Approaches to Hardware Design of Mobile Robot Platforms** Dr Swagat Kumar, Centre of Excellence in ICT, IIT Rajasthan, Jodhpur, India.
1620 – 1640	**Stable Coordinated Platooning by a Group of Mobile Robots** Dr Anjan Kumar Ray, ISRC, University of Ulster, Magee Campus, UK.
1640 – 1700	**Hierarchical Skill Building** Dr Lorenzo Riano, ISRC, University of Ulster, Magee Campus, UK.
1700 - 1830	**Visit to ISRC labs**
1930 – 2130	Workshop Dinner in Custom House

July 8, 2011

Time slot	**Title**
0900 – 1100	Session-4 Chair: Professor Sunil Kumar Agrawal Co-chair: Dr Tomas Ward
0900 – 0940	**Partner Robots for Mental Health Care - Japanese Challenge towards Practical Robots** Professor Goro Obinata, University of Nagoya, Japan.
0940 – 1020	**Learning to Control Robotic Systems** Professor Laxmidhar Behera, Indian Institute of Technology, Kanpur, India.
1020 – 1100	**Cooperative Control of Multi-robot Systems for Societal Benefit** Professor Debasish Ghose, Indian Institute of Science, Banglore, India.
1100 – 1120	Coffee Break
1120 – 1320	Session-5 Chair: Professor Liam Maguire Co-chair: Dr Damien Coyle
1120 - 1200	**Robotic Exoskeletons for Functional Training of the Motor Impaired** Professor Sunil Kumar Agrawal, University of Delaware, USA.
1200 – 1240	**Design of an optimal finger exoskeleton and its control based on human hand motion data** Dr Ashish Dutta, Indian Institute of Technology, Kanpur, India.
1240 – 1320	**Control of rehabilitation robot FRIEND by BCI: Experiences, new developments and future applications** Professor Axel Gräser, University of Bremen, Germany.
1320 – 1430	**Lunch and poster viewing**
1430 – 1600	Session-6 Panel discussion, Moderator: Dr Girijesh Prasad
1430 - 1600	Panel discussion on the **Fusion of BCI and Assistive Robotics** **Each panel member will speak for 5 minutes followed by interactive discussion involving all the workshop attendees.** **Panellists:** Dr Christoph Guger, Dr Gernot Müller-Putz, Dr Tomas Ward, Professor Sunil Kumar Agrawal, Professor Debasish Ghose, Professor Goro Obinata , Professor Axel Gräser
1600 – 1620	Coffee Break
1620 – 1820	Session-7 Chair: Dr Christoph Guger
1620 – 1820	g.tec BCI workshop and demo
1820	Closing

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Possibilities for Human Enhancement through BCI

Kevin Warwick
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It is usually the case that a brain computer interface (BCI) is employed with therapy or rehabilitation in mind. In this sense the BCI is used to restore or repair a lost or malfunctioning ability. The most ubiquitous neural prosthesis in humans is the cochlear implant [1]. This prosthesis is designed to elicit patterns of neural activity via an array of electrodes implanted into the patient's cochlea. It has a specific purpose. The same is true with regard to deep brain stimulating (DBS) electrodes as employed for Parkinson's Disease, Epilepsy or Tourette's Syndrome. These normally operate in a unidirectional (stimulating only) fashion, however DBS electrodes can also be used to monitor brain activity which can be input to an AI system in an attempt to learn more about functioning in areas of the brain [2].

Alternatively BCIs can be employed to provide humans with abilities that they do not normally have or at least to extend their abilities beyond the human norm. The microelectrode array (Figure 1) has been implanted in order to test *bidirectional* functionality in a series of experiments. Stimulation currents allow information to be sent to the user, while control signals can also be decoded from neural activity to indicate intent [4]. In this way a number of enhancement possibilities have been tested [1-4]:

1. Extending neural control (with feedback) over networks.
2. Direct neural communication.
3. Extending the range of sensory input.
4. Direct prosthesis control by means of neural signals.

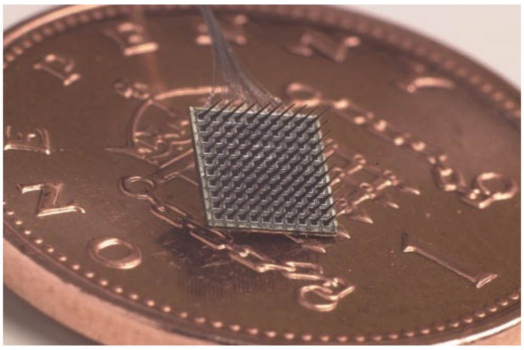

Figure 1: A 100 electrode, 4X4mm Microelectrode Array

Such experimentation clearly opens up a wide range of technical possibilities that only further experimentation will confirm one way or another. However it also raises numerous ethical questions as to the future employment of BCIs. In this paper the experiments, possibilities and issues will be discussed.

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Developing practical brain-computer interfaces: Opportunities and challenges

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The possibility of brain-computer communication based on the electroencephalogram (EEG) has been discussed almost four decades ago [4]. In another pioneering work, Farwell and Donchin described the use of evoked potentials for communication [1]. Up to the early 2000s, no more than 5 groups were active in brain-computer interface (BCI) research. Now, about 200-300 laboratories are focused on this work. This dramatic growth has been driven by high performance and low cost of computing power and related instrumentation, increased understanding on normal and abnormal brain functions, and improved methods for decoding brain signals in real time. As a result, the performance and usability of BCI systems have advanced dramatically over the past several years.

BCI systems can be described by the following characteristics: (i) invasive (electrocorticogram (ECoG), spikes) or non-invasive (EEG, NIRS (near infrared-spectroscopy), fMRI (functional magnetic resonance imaging), MEG (magnetoencephalogram)) systems [5, 2, 3], (ii) portable (EEG) or stationary (fMRI, ECoG, spikes), (iii) according to application area (spelling, wheelchair control, brain painting, research,…), (iv) type of BCI principle used (P300, SSVEP (steady-state visual evoked potential), motor imagery, slow cortical potentials) (v) speed and accuracy, (vi) training time and reliability, (vii) synchronous and asynchronous, (viii) low cost (EEG, NIRS) and high cost (MEG, fMRI, spikes), (ix) degrees of freedom.

The advantages and disadvantages of the different BCI systems will be discussed based on the BCI Award 2010 with 57 BCI project submissions. Of particular interest is the high percentage of real-time BCI implementations that exist nowadays. Motor imagery is still the mostly used strategy to control a BCI, followed by P300 and SSVEP. It is also not surprising that mostly EEG-based BCI systems are used because they are easier to handle and are cheaper. Thus far it is not known whether a BCI system can be developed that utilizes activity from more central structures of the brain. The mostly implemented application is spelling, ahead of general control and stroke rehabilitation, wheelchair/robot or Internet control.

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EEG-fNIRS fusion for Practical Brain Computer Interfaces

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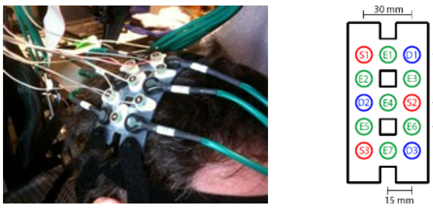
It is speculated that motor rehabilitation following stroke may be enhanced through the use of BCI which monitors patient's motor cortical effort either to drive a robotic assistance device or provide other types of feedback capable of driving the neuroplastic processes underlying recovery. A number of studies are taking place worldwide which aim to resolve this matter. In the event that such an intervention is of utility there are a number of practical matters, which must be addressed in order that such neural-activated systems see wide scale deployment in rehabilitation hospitals, out-patient clinics and perhaps most importantly of all, in the home setting. One of the most pressing is the development of sensor systems, which can be applied quickly, easily and preferably without gel. In order to maximize patient rehabilitation therapy compliance and minimize frustration for users such sensor systems should have the property that they can be easily applied to the head with a minimal instrumentation process. We believe this can be achieved through the use of a small scalp area from which to extract the required brain activity signal. Given the localization of motor function on the cortex via primary and supplementary motor areas, intrinsically this is not a problem. Electroencephalography (EEG) electrode arrangements can be designed to optimize for this which use a much smaller set of leads than the common 32 (or more) channel systems favored in neuroscience research laboratories. In addition, new technologies in electrode design are emerging such as dry and even non-contact electrodes. However such technologies do not yet have the same signal-to-noise performance of conventional systems and therefore what is gained in terms of electrodes and site preparation is lost in terms of poorer measurement capability. We believe that this problem can be overcome through extracting more information from a given area of scalp by augmenting the measurement with a complementary modality, in this case functional near infrared spectroscopy (fNIRS). fNIRS relies on geometrical arrangements of optodes, which do not limit the placements of electrodes associated with EEG when measuring over the same brain region. Consequently a hybrid sensor BCI making use of such an arrangement is theoretically capable of extracting more signal during brain activation. Further, the differing aspects of brain physiology underlying the measurement allow interpretation of the data as a compound signal, which more completely characterizes the active cortical area.

Figure 1 below shows an instance of our proposed EEG/fNIRS system. Using this device we conducted a small set of experiments for two sets of healthy subjects engaged in overt movement and imagined movement tasks.
A standard motor paradigm was employed in which subjects engaged in forty trials of motor activity for overt and imagined upper limb activity (separate sessions). EEG was processed for event related synchronization/ desynchronization (ERS/ERD) according to standard methods [1]. fNIRS was measured using a TechEN CW6 instrument at 690nm and 830nm. Optical density measurements were converted to changes in oxy- and deoxy-hemoglobin (HbO, HbR) using standard techniques [1]. Standard features for each modality were used for classification purposes (EEG: transient changes in relative contributions of key spectral regions. fNIRS: elevation of HbO, depression of HbR)[1] .

In both cases we demonstrated a 10% increase in classification accuracy when a combined optical and electrical feature is used over each modality used in isolation.



Channel Num	fNIRS Src	Det	EEG
1	S1	D1	E1
2	S1	D2	E2
3	S2	D1	E3
4	S2	D2	E4
5	S3	D2	E5
6	S2	D3	E6
7	S3	D3	E7

Figure 1: (a) Dual optode/electrode in situ, (b) geometry and (c) measurement type.

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Hybrid brain-computer interfaces: current state and future directions

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Persons with movement disabilities can use a wide range of assistive devices (ADs). The set of ADs ranges from simple switches connected to a remote controller to complex sensors (e.g., mouth mouse) attached to a computer and to eye tracking systems. All of these systems work very well after being adjusted individually for each person. However, there are still situations where the systems do not work properly, e.g., when residual muscles become fatigued or users have such severe disabilities that no movement is possible. In such situations, a Brain-Computer Interface (BCI) might be the only available option, since it uses brain signals (usually the electroencephalogram, EEG) for control without requiring any movement whatsoever.
BCIs are systems that establish a direct connection between the human brain and a computer, thus providing an additional communication channel. As noted, some people use a BCI because their disabilities make it impossible to use any interface requiring movement. BCIs can also be used to control neuroprostheses in patients suffering from a high spinal cord injury. After 20 years of research and development, Brain-Computer Interface technology is ready to leave the lab and to be used in practical applications in real world settings such as homes or hospitals.

A BCI could replace an existing AD. However, it would be even better to couple the BCI with the existing AD and develop a new system called a hybrid BCI (hBCI) [1,2]. Ideally, an hBCI should let the user extend the types of inputs available to an assistive technology, or choose not to use the BCI at all. The hBCI might decide which input channel(s) offer(s) the most reliable signal(s) and switch between input channels to improve information transfer rate, usability, or other factors, or could instead fuse various input channels.
In the past as well as in the present, various studies about hBCIs have been conducted, but they have in common that they all combine a BCI with another BCI (using different brain signals) or a BCI with another biosignal. In general, a hBCI does not depend on the BCI as an input. Instead, it simply allows the BCI to function as an input channel when the BCI could increase the overall performance for that user. The hBCI can perform fusion to switch between multiple inputs, but (depending on the configuration) can also weight signals and combine/fuse them to achieve one control signal from a combination of multiple inputs.

The principle of such an hBCI can be explained as following: in addition to the EEG-based BCI, there are other input and control signals possible. These include other biosignals as well as signals from manual controls such as from ADs (e.g., mouth mouse, push buttons, …). A "fusion" generates a new control signal out of all inputs. Besides a quality check (e.g., artifact detection), those signals will be weighted and fused to a control signal, or the most reliable one will be chosen. Followed by the so-called "shared control", sensor signals from the application (neuroprosthesis, software, assistive robot) will also be included and used to generate an accurate final control signal.
One major goal is to bring the BCI technology to a level where it can be used in a maximum number of scenarios in a simple way. To achieve this, the hBCI must be able to operate reliably for long periods, recognizing and adapting to changes as it does so. Reaching this goal requires that many different subsystems in the hBCI are able to work together. Examples include standard BCI processing, post processing (error potentials), mental state recognition (fatigue), artifact detection, adaptation of classifiers, and surveillance of signal quality (including EEG signals and those from additional input devices).

- **Acknowledgements**

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Robotic Exoskeletons for Functional Training of the Motor Impaired

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Robotics is emerging as a promising tool for training of human functional movements. This talk will describe novel designs of an upper arm exoskeleton and two lower extremity exoskeletons with their clinical evaluation for neuro-motor training. ALEX is an Actively driven Leg Exoskeleton which can modulate the foot trajectory using motors at the joints. This exoskeleton was tested on 36 healthy subjects with basic neuroscience question if short-term changes in healthy gait is possible by training [1]. The exoskeleton was also pilot tested on chronic stroke survivors over six-weeks [2]. GBO is a Gravity Balancing un-motorized Orthosis which can alter gravity at the hip and knee joints during swing phase of the gait [3]. This exoskeleton was pilot tested on a chronic stroke survivor, when gravity assistance was decreased over time [4]. This research is supported by grants from the National Institute of Health in USA.

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Cooperative Control of Multi-robot Systems for Societal Benefit

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Although the field of robotics has reached a high level of sophistication, it is yet to live up to its original idea of creating an artificial assistant to a human which could share the human's tedious chores. Over the past decades researchers all over the world have concentrated on the all-important question of what a robot can be made to do when deployed as an inherent infrastructural device in a human society. It was soon realized that there are several tasks that may need more than one robot to make the task easier or to be accomplished. This brings us to the field of cooperative multi-robot systems which works on the principle of "simple rules, complex behaviour".

The first part of this talk will focus on some of the mathematical background to the theory of cooperative control as applied to the problem of agreement or consensus. The second part of the talk will introduce the notion of swarm intelligence and present some recently developed algorithms inspired from the biological world that can be used by a multi-robot system to locate signal sources (chemical, olfactory, thermal, or nuclear) that are a hazard to the human society. We will particularly focus on an algorithm based on the behaviour of glowworms or fireflies. The third and concluding part of this talk will look at the human capability of navigating through obstacle infested environments depending solely on the capability of vision. We will describe a vision based obstacle avoidance algorithm that can be used very effectively to guide smart robotic wheelchairs and walking canes for the blind. We will discuss how the notion of cooperation between several such vision sensors can be made more effective by creating an interface with the human in the loop.

Partner Robots for Mental Health Care
- Japanese Challenge toward Practical Robots -

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- **Introduction**

The Japanese situation around the population characteristics and the economics requires partner robots for assisting care-givers. This talk introduces current status of Japanese partner robots with emphasis on mental health care. Several types of pet robots or communication robots have been developed and tested on their effectiveness during these decades in Japan. Some of them are developed for mental health care of elderly people who live alone, and some robots are designed for autistic children. First, we describe the requirements for the robots, and the design specifications which meet those requirements. Second, we show the results of questionnaire in case studies with elderly people and autistic children. User's closeness of link with the robot is dependent upon user's life style and communication capability. Finally, the discussions on the elderly's acceptancy and on autistic children's acceptancy for such robots are given.

- **Methods**

The robot we used for collecting the reponses of test subjects is shown in Fig.1. It has a speaker, microphones, CCD camera, several sensors, and motor-driven wheels. The most important feature is voice recognition through the microphones, which can be used for verbal communications with an appropriate algorithm. The facial expressions can be controlled within the pre-designed positions and orientations of the head, the eyes and the mouse with variable luminant. We set several experimental conditions with the controls, and collect the responses from the subjects which were asked to do something with the communication robots. One experiment was designed to compare the reactions of elderly subjects in different life styles. The other experiment was planned for putting lights on the differences of autistic cildren's responses to the robot and the care giver. We examined the effect of communication robot on autisitic children's attention and motivation to join trainings.

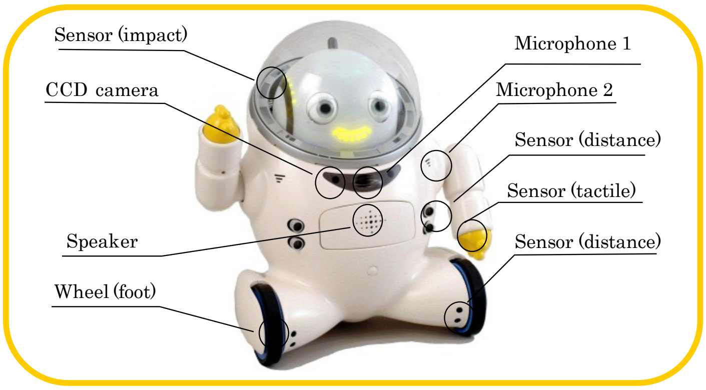

Fig.1. Robot for communication ("if bot").

- **Results**

The results are summarized as follows. In the experiments of collecting required information through web browsers and the communication robot, we found the clear difference in the answers to the questionnaires while using web browser or the robot. This indicates that people feel some difference between standard personal computer setup and the communication robot while using those. In the answers to the questions on the recongnition rate of the robot in the verbal communications, elderly people who live alone showed high scores in comparison with elderly peole who live with thier family. In the experiments with autistic children, the chilren-robot interaction was more effected than the children-human(care giver) interaction. The mean of eye contact and response in verbal communication with the robot is significantly higher than those with human.

- **Conclusions**

The results show that the communication robots make differences while people using those. We can use commercially available communication robots in a special aspect for giving care to some of elderly people and autistic children. However, we cannot identify the origin of such effects or differences with communication robots. At this stage, there exist a lot of discussions on the requirements for the robots and the design specifications which meet those requirements. Further research will be required.

- **Acknowledgments**

These experiments described in this paper were partly supported by Japanese Ministry of Education, and conducted with my colleagues Dr. K. Matsumoto, Dr. H. Takehashi, T. Suzuki, N. Takeda and J. Lee. The author would like to acknowledge them.

Control of rehabilitation robot FRIEND by BCI: Experiences, new developments and future applications

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In this paper we consider the rehabilitation robot FRIEND which is designed to support completely paralysed people in daily life activities but also allow them a reintegration in professional life and give them part time independence from nursing and supporting staff. For a reliable and really helpful support system it is necessary that the user with support of FRIEND can act independently in a human centered and to some kind of flexible/ variable environment. We cannot assume a static and fixed environment as it is available in industrial robot environments. The request for independence of at least 90 minutes from human support requires not only the automation of single isolated tasks by the robot but also the automation of complete action sequences. An example of such an action sequence arises if e.g. eating with the support of FRIEND is considered. The action sequence may start with the opening of the fridge, taking out the preferred meal, heat it in the microwave, take the meal to the tray at the wheelchair and feed finally the user with the meal in a sequence and the way that is determined by the user. The variability in the environment and in the boundary conditions of the task may be of many different reasons. They reach from changing illumination to variable surroundings and multiple objects of the same class to be handled. Acting reliably and safely in such environment leads to very complex robot controller which is beyond today's available theoretical and practical solutions. Shared control mode is the approach which is chosen to limit the complexity of the robot control task and to ensure robustness of control and safe operation. Shared control mode means here that whenever possible the FRIEND skills are used to carry out the task automatically. FRIEND has a set of sensors (image sensors, force torque sensors) to support this mode and allow a sensor based control of the robot arm. In case that the robot cannot fulfill the task autonomously the user may step in and take over control with its mental capabilities that are superior to the robot control capabilities.

Shared control mode requires that the user every time can take over control of the robot and that the user may issue commands at a high or low abstraction level. A command on a high abstraction level is e.g. "poor in a drink" or e.g. specifying an object out of several similar ones which are available in a scene. Examples for low level commands are e.g. the specification of a direct motion of the robot arm or the control of the video camera which gather the necessary information for visual based robot control. To control FRIEND there are different input devices available that matches the specific requirements of the disabled user and the requirements of the task. Brain Computer Interface is one of the possible command devices which has on one hand a very high potential as a universal device but on the other hand still several shortcomings. One of the main shortcomings is the low Information transfer (ITR) rate especially if we compare it with the requirements for direct robot control.

The Bremen BCI uses presently SSVEP and ERD/ERS as communication paradigm for user interface and for robot control. In the presentation the approaches are described in more detail and also the results that are achieved with different user groups. To enhance the ITR advanced signal processing methods may be used but also the training of the user comes into play and finally the preparation of the user is of crucial importance.

In the presentation we will discuss the different approaches taken and the lessons learned. We will start with the description of the different algorithms which are used, the ITR achieved and the dependence from the demographic dates of the users. The coupling of the BCI with the robot control and the layouts of the user interface are considered in more detail. Finally we will discuss the possible combination of BCI and visual data acquisition which are to be combined in a new head cap and how this device may improve the use of BCI in robot control.

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Surface EMG Signal is Less Gaussian at Lower Contraction Levels

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Surface Electromyogram (sEMG) signal is a non-invasive measurement of the electrical activity of the closely spaced muscles recorded from the surface of the skin and it represents the approximate summation of the electrical activity passing through the muscle and thought to reflect the level of muscular activity. It has been widely used for prosthetic control, assistive device control as well as functional electrical stimulation because of its non invasiveness as well as ease of use.

It has been proposed that a Gaussian density function can model the probability density function (pdf) of sEMG recorded in constant-force and non-fatiguing contraction strength conditions [1]. It has also been reported that during low intensity isometric contractions, the pdf of the sEMG signal is more peaked near zero than the Gaussian distribution (super-Gaussian) with a tendency for the kurtosis values to decrease with increasing contraction level [2]. Negentropy analysis of the EMGs showed that the non-Gaussianity level of the sEMG signal depends on the muscular contraction level such that the increment in the contraction level shifts the sEMG pdfs towards a Gaussian distribution [3]. Kaplains et al. [4] characterized the Gaussianity of the signal by investigating the bicoherence index of the EMG measurement. They reported that the EMGs are highly non-Gaussian at low and high levels of force while being in its maximum Gaussianity at the mid-level of maximum voluntary contraction. Paradoxically, Hussian et al. [5] used the bicoherence index to test the Gaussianity of the sEMG signal and showed that the sEMG signal becomes less Gaussian with increased walking speed force (increase in mean voluntary contraction). We revisited this problem and investigated the suitability of the EMG bicoherence index to characterize the non-Gaussianity level of sEMG.

Four subjects controlled a myoelectric cursor by making isometric muscular contractions. The smoothed and rectified EMG determined cursor position along a vertical axis. EMG signals were recorded from *abductor pollicis brevis* (APB) and *flexor carpi radialis* (FCR) muscles. We recorded the EMGs in seven different force levels (50 trials at each level) with a sampling frequency of 10 khz including the maximum voluntary contraction level (5 trials only). Visual feedback was provided using the computer monitor.

In all four subjects and for both muscles, kurtosis values monotonically decreased when the contraction level increased. This finding is consistent with the predictions of the Central Limit Theorem because the increases in the contraction level will likely cause recruitment of more motor units. Higher kurtosis values at low intensity contractions imply that the EMG pdfs are more peaked at zero at low intensity contractions but become closer to a Gaussian distribution function at higher force levels. However, in contrast to [4] and [5], we did not observe any muscle activity related to the modulation of the computed bicoherence index perhaps because the EMG signal has a reasonably symmetric pdf.

In conclusion, our kurtosis analysis results confirm that the EMG pdf is less Gaussian at low muscle contraction levels. This feature of the sEMG signal has proved effective in control of the myoelectric prostheses [3], although the problem of accurate computation in real-time remains a practical challenge.

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BCI-supported humanoid robots as semi-autonomous personal assistants

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We propose to combine state-of-the-art robotics technology with an EEG-based brain-robot interface (BRI). By integrating semi-autonomous robot behavior into a partially BRI-supported system, rather complex robots with a high number of DOFs can be controlled by only a small set of available BRI commands. This approach allows for using the EEG to construct advanced and complex assistive systems for patients with severe motor-control deficits. Depending on the degree of impairment, different types of assistive technology are required. We have identified two major fields of application: (1) tasks related to the manipulation of objects and (2) social (human-human) interaction.

We have developed an EEG-based, hybrid BRI. The interface exploits the P300 potential and ERD evoked by motor imagery. It is truly hybrid, constantly scanning the 16-channel stream of EEG data for both patterns in a parallel, asynchronous fashion (see [1]).

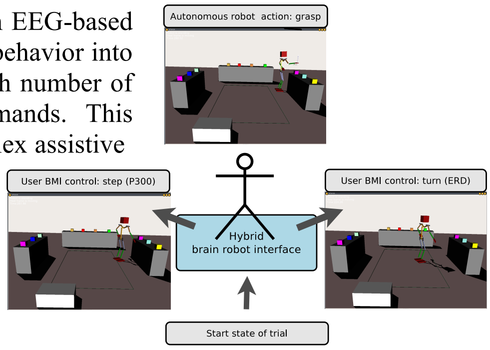

Fig. 1: Simulation of the scenario as conducted in the lab with the physical HHRR robot.

Humanoid robots are a very interesting platform for assistant robots based on BRIs. Their outstanding feature is that they have the same embodiment as humans. In the future they may provide a kind of surrogate body for patients no longer able to use their own body. We validated this concept in empirical studies. Our BRI was connected to two different humanoid robots: *Honda's Humanoid Research Robot* (HHRR) [2] for object manipulation and the *iCub robot* [3] for social interaction. Both systems share three major features: (1) they exploit the same brain activity patterns in an asynchronous, hybrid fashion; (2) they make use of an advanced fusion of controllers; (3) only specific, high-level action sequences are explicitly triggered by the user, while all other low-level actions are processed autonomously by the robot.

Table 1: Action numbers (avg. over participants) to reach each item.

Trial	BRI control			Perfect control		
	All	Steps (P300)	Turns (ERD)	All	Steps	Turns
1	15.67	10.17	5.50	5	4	1
2	9.17	7.00	2.17	5	4	1
3	12.50	7.67	4.83	7	3	4
4	11.67	6.67	5.00	6	3	3
5	17.67	9.00	8.67	7	3	4
All	66.68	40.51	26.17	30	17	13

We created a "shopping" scenario in our lab for the object manipulation task with HHRR (Fig. 1). The task of the user was to collect several items. By using the BRI for triggering steps (P300 controlled) and turns (ERD controlled) of the robot, the user could navigate the robot to the items. The robot accomplished all other actions, i.e. grasping and carrying the item to the user, autonomously. To assess system performance, we compared the number of user-triggered actions to the ideal number of actions theoretically needed. Table 1 gives these results.

For the social interaction task, we created a scenario where the iCub robot functions as a mediator of essential interaction aspects like gesturing or facial expressions that are no longer available for paralyzed patients (Fig. 2). The BRI triggers robot head movements so that the user can virtually look around using iCub eye cameras and then select a particular gesture/facial expression combination. The robot thus serves as a surrogate display of the user's emotional state. So far, we conducted an initial case study where we successfully showed the functionality of the approach.

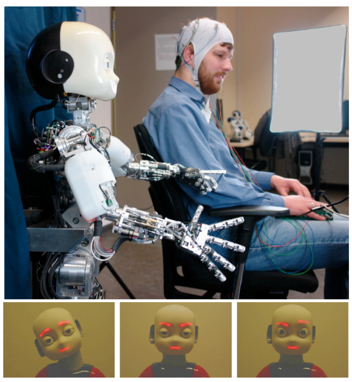

Fig. 2: Top: Scene from our iCub study. Bottom: Some facial expressions the robot can display.

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Digit-Ease: Wearable Rehab Technology for Automatic Measurement of Patients Rheumatoid Arthritic Hand Movement

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Rheumatoid Arthritis (RA) affects 0.5% to 1% of the general population [1]. The prediction and prognosis of the disease varies for each individual and its course can detrimentally affect the psychosocial condition of the patient. Clinicians and Therapists aim to quickly diagnose and treat those with this debilitating disease. Detection relies heavily on invasive x-rays or manual evaluation methods which are dependent on training and can vary between observers. Digit-Ease will provide medical clinicians with a Range of Motion (ROM) tool to assist medical clinicians with accurate angular measurement of hand joints and the detection of joint stiffness.

RA is a disease which affects the musculoskeletal system, including bones, joints, muscles and tendons that contribute to loss of function and difficulties in performing activities of daily living (ADL). Clinicians and Therapists aim to quickly diagnose and treat those with this debilitating disease through treatment programs and education [2]. A time consuming examination assesses the clinical appearance of hands and fingers. A goniometer measures individual finger and thumb joints. A tape measure determines thumb-index finger web space and distal phalanx-palm distance in centimetres. Outcomes are easily influenced by the observers training and experience.

Digit-Ease is an intelligent computing system that will consist of a wearable glove measurement tool [3, 4] and a 3D interface as shown in Figure 1. Real time data captured from each glove sensor will be displayed numerically and graphically. It will accurately quantify patients' flexion, extension, adduction and abduction of finger and thumb joint movements in degrees, maximum and minimum joint range and compare joint range with normal ROM values [5] to determine the degree of deformity of the hand and stiffness of moving finger joints. Digit-Ease will simultaneously record angles from multiple fingers to detect previously unidentifiable movement patterns. It will measure a shift in the position of fingers in relation to the direction of the thumb by measuring web space and recording the minimum, maximum and average values during a number of tests to analyse joint movement and identify areas for Joint Protection benefit. Data will be recorded and used for future comparison analysis. It will be the first ambulatory system to detect joint stiffness 'at home' and will help quantify and understand the symptom of 'early morning stiffness'.

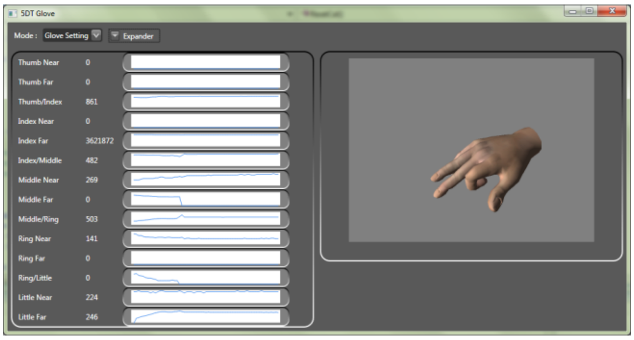

Figure 1a: 3D interface.

Figure 1b: wearable glove

Standard robotic tests using Shadow Hand [6] will validate readings obtained from the final prototype glove to determine the angular accuracy of each joint and provide calibration testing.

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Hybrid BCI controlled FES for rehabilitation of the hand in acute tetraplegic patients

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Background:
Functional electrical stimulation (FES) is a widely adopted method for motor rehabilitation of the upper extremities. Typically a patient has no control over the stimulator, which is switched on and off automatically in a predefined manner. The advent of Brain-Computer Interface has opened up new possibilities for patients with an injury to the Central Nervous System, providing them control over the FES stimulator [1]. In addition to this, motor imagination controlled by BCI should promote rehabilitation facilitating excitation of afferent pathways activated by FES.

Methods:
Two right-handed acute Spinal Cord injured patients with tetraplegia (SCI level C5) participated in the study. They received electrical stimulation of their hand extensor muscles. Hybrid EEG BCI was based on a combination of the mu rhythm during motor imagination and the eyes-closed occipital alpha. The exact band was based on ERD/ERS maps during cue based imagination. The FES stimulator was activated when the Power Spectral Density (PSD) over the sensory-motor area *dropped* below the empirically determined threshold. The FES stimulator was deactivated when PSD over the occipital region (O1 or O2) *exceeded* a predefined threshold for 1s. A restriction for choosing thresholds was that the threshold values do not cause false positive activation/deactivation of FES during 2 min eyes-open state (with 1s criteria). A period of 1s was chosen empirically. PSD was calculated using g.tec RT.Analyse Matlab Simulink blocks.

Results:
Both participants learned to activate a stimulator using the mu rhythm (8-10 Hz) during the first experimental session. For training asynchronous imagination patients were looking at a GUI. FES was automatically deactivated after 10s. During the fourth session they were introduced to a hybrid BCI and were able to use it immediately. Once parameters were set, there was no false positive activation/deactivation. Figure 1 up, shows the mu rhythm PSD in S1, recorded over CF4-CP4 during imagination/attempt to extend the left hand. Thick line shows the stimulation current (ramp pulse, 15mA/250 μs, frequency 33 Hz). Figure 1 down shows PSD over the occipital alpha (O1) and the same stimulation current (amplitude enlarged 5 times). When the mu rhythm *dropped* below 0.3 μV^2 the stimulator was switched ON and when the occipital alpha *rose above* 50 μV^2 the stimulator was switched OFF. Note that the mu rhythm was low during the period of stimulation, even though the person had stop imagining, so it cannot be used as a command signal to deactivate the stimulator.

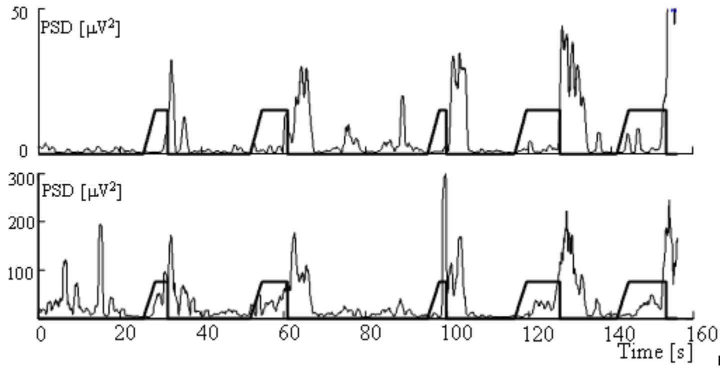

Figure 1. Mu rhythm (upper graph), occipital alpha

Conclusion:
This study demonstrates the feasibility of using a BCI-FES system for rehabilitation purposes in tetraplegic patients. Further work is needed to establish a clinical advantage of BCI-FES over the conventional FES strategy.

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Towards natural hands-free human-robot interaction – methods and applications

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Natural human-human interaction involves the use of various interaction modalities in parallel. To improve naturalness of human-robot interaction (HRI), interfaces should not be uni-modal either. For users with motor-control deficits, manual interaction is not always an option, however, they do not necessarily need to restrict interaction to a single non-manual modality. Instead, we suggest combining brain-computer interfaces (BCIs) with gaze interfaces and other bio-physiological measurements for hands-free interaction. This will not only increase the number of control dimensions for assistive robotic devices, but cortical and oculomotor data may also complement each other and thus make HRI more reliable. The subsequent paragraphs provide an overview of some ongoing work in this field at the Cognitive Interaction Technology Excellence Center (CITEC) at Bielefeld University.

Fig. 1: Combining cortical and oculomotor data tracking for application control.

Fig. 2: Tangible Active Objects (TAOs) as mediators in hands-free HRI.

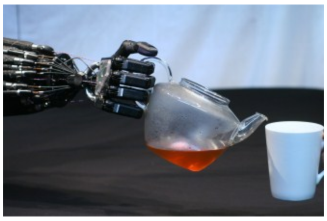

Fig. 3: Assistant robot pouring a cup of tea.

Apart from hybrid BCIs for humanoid robots as semi-autonomous personal assistants [1], we implemented BRECI, a brain-eye computer interface based on brain signals and oculomotor measurements [2]. BRECI on-line detects ERD evoked by motor imagery which, in a sample car-racing simulation, is used for steering. In addition, users gaze-contingently control driving speed (see Fig. 1). After proof of concept, we can now port the cross-modal interface and allow BRECI to control assistive robotic devices. These will be self-moving vehicles for increasing users' mobility or semi-autonomous robots for household tasks. Robots may come as AR-drones that can navigate more easily in cluttered environments.

We also investigate machine-mediated collaboration between humans, processing cortical activity in real time from two or more partners. Partners coordinate joint actions, controlling one or several robot-like devices (TAOs, see Fig. 2) which serve as mediators [3]. This can be instrumental to rehabilitation robotics where assistant robots should intuitively mediate between patient and environment or caretaker. Additional oculomotor data can provide vital clues to turn-taking, while transferring gaze positions may help solving joint tasks in robot-mediated interaction. In contrast to current BCI approaches, our triadic setting allows for investigating neurophysiological foundations of human-human interaction and for accessing adaptation processes in machine-meditated interaction – an aspect of great relevance for rehabilitation robotics and as yet only little explored.

Another project addresses the modelling of multi-component bio-physiological data for adaptive human-machine interfaces. Based on on-line EEG measurements and other bio-physiological data such as skin conductance and oculomotor activity, we are developing models that enable the design of multi-user human-machine interfaces, mapping multiple components within the different data streams onto distinct functionalities. In contrast to established methods, the integration of different EEG components and other bio-physiological measures enhances the interface flexibility. Signal combination should also make the system more robust as problems with one signal can be compensated by the others. Therefore, more sophisticated applications in assistive robotics (see Fig. 3) that use different signals as different input channels become possible.

- **Acknowledgements**

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Decoding movement and laterality from human subthalamic local field potentials for neuro-prosthetic applications

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Background

A neuro-motor prosthesis is a device intended to provide movement signals from the brain so that neurologically impaired patients can interact with their environment to perform daily tasks. Several studies in monkeys [1] and humans [2] have shown that the primary motor cortex (M1) could potentially provide movement-related signals to control assistive devices for paralyzed patients. However, other areas of the brain may provide alternative or additional information. Deep brain stimulation (DBS) offers a unique interface to sense and intervene the human brain circuits. The function of the basal ganglia and thalamus in motor control has been studied with invasive recordings of local field potentials (LFPs). Loukas and Brown demonstrated that oscillatory LFP activity in the subthalamic nucleus (STN) is directly or indirectly involved in motor preparation [3], suggesting that useful movement signals may be available in this area as well. This study aims at decoding the neural activity related to human voluntary movements by identifying features and patterns related to movement execution and laterality as a means to judge the suitability of this area for use in neuro-prosthetics.

Methods

LFPs were recorded from bilateral STN via implanted DBS electrodes in patients with Parkinson's disease while they performed left or right finger clicking task stipulated via visually guided cues. The STN LFPs were low-pass filtered at 90Hz and then the frequency dependent components were extracted as δ = 0-4Hz, θ = 4-8Hz, α = 8-12Hz, low β = 12-20Hz, high β = 20-32Hz, low γ = 32-60Hz and high γ = 60-90Hz frequency bands using wavelet packet transform. The instantaneous amplitude of each component was computed using the Hilbert transform. The features were defined as the average amplitude within each of five consecutive 100ms windows located around the motor response. A Bayesian classifier incorporating these features was designed for optimal feature selection and classification. The features were ranked (highest to lowest) according to their individual classification accuracies and then a subset of features was accumulatively selected either when the classification rate reached a maximum or it plateaued. The classifier was validated using 10-fold cross-validation.

Results

Consistent significant amplitude decreases in the β bands and increases in the γ bands were observed during the motor response. Both movement, i.e. resting or action, and laterality, i.e., left or right clicking were evaluated from four subjects. The average accuracy obtained was 88% for identifying movement, with significant contribution from θ, β and high γ bands features. The following laterality classification achieved 67% average accuracy with significant contribution from θ, α and high γ bands features. The potential possibility of early identification of movement execution was also evaluated and the initial analysis demonstrated that it is possible around 250ms before the onset of the actual movement.

Conclusions

The results suggest that the neural activity in human STN contain movement information. These findings may enhance our understanding on the underlying processes in STN for voluntary movement control and its important implications for the development of neuro-motor prostheses in humans. Thus, movement information from STN areas might be useful in place of M1 if the M1 is damaged or in combination with M1 cortex activity for enhanced movement identification toward neuro-prosthetic applications.

Acknowledgements

This work was supported by the UK Engineering and Physical Sciences Research Council (EPSRC) and ISVR Rayleigh Scholarship, University of Southampton, UK.

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Motor Imagery Learning using a Brain-Computer Interface with Auditory Feedback

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It is common to display data visually in most cases as vision is generally accepted as our most important sense. This communication channel is however not available to everyone such as those with sight problems or those in advanced stages motor-neurone disease making them ideal candidates for a brain-computer interface (BCI) which makes use of the auditory channel to relay information to the user. This study aims to assess the potential benefits that auditory feedback affords in the absence of any visual feedback when voluntarily modulating sensorimotor rhythms. Six healthy volunteers with normal vision and hearing took part in 10 sessions. Three were offered visual feedback whilst 3 were given auditory feedback. A training session (Figure 1) was necessary in order to tune parameters specific to each participant, further details of which can be found in [1][2] where the complete BCI is described in detail.

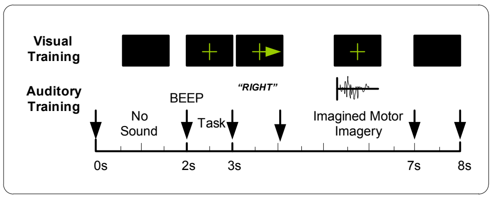

Figure 1: Training Session Timings

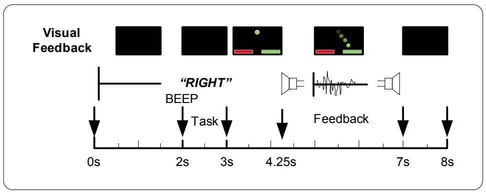

Figure 3: Feedback Session Timings

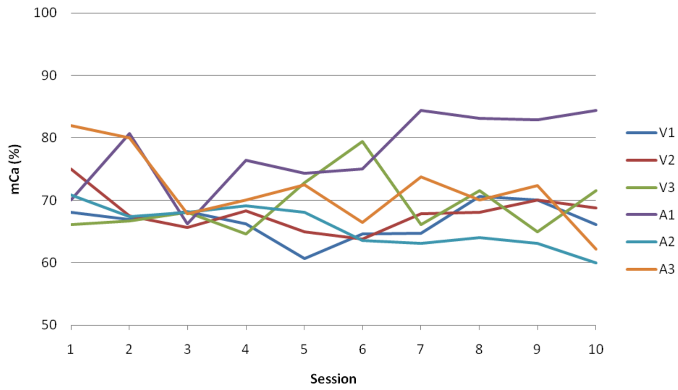

Figure 2: Results for All Participants

On presentation of the task the subject was required to imagine ipsilateral arm movement and received feedback (Figure 2). The visual task was to direct the ball toward the green basket and this was achieved by voluntary sensorimotor imagery. The auditory group received feedback in order to inform the participant of changes in the azimuth or horizontal positioning of a sound source.

The auditory group performed better overall with an average maximum (peak) mCA (mean classification accuracy) of 71.73% (S.D. ± 2.77) when compared against the visual group at 67.94% (S.D. ± 1.5). Everyone who took part attained 70% accuracy at least once during the study (**Figure 2**); however, only one auditory subject was able to do this for more than 6 sessions. This study demonstrates the feasibility of the use of auditory feedback as a replacement for its visual equivalent. A follow-up study will make use of a musical 'palette' which will contain various styles of musical feedback. The study continues and will culminate with the completion of 10 visual and 10 auditory participants each taking part in 10 sessions. It is planned to use a modified set of earphones in future studies which will not block the ear canal completely and will allow the participant to not only hear audio from the system, but also to hear sounds from their environment aiding in communication.

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Game Theory: A Potential Tool for the Design and Analysis of Patient-Robot Interaction Strategies

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Designing suitable robotic controllers for automating movement-based rehabilitation therapy requires an understanding of the interaction between patient and therapist. Current approaches do not take into account the highly dynamic and interdependent nature of this relationship. We feel that a better understand can be accomplished through framing the interaction as a problem in game theory. Game Theory is a branch of mathematical analysis developed to study social decision making in situations of competition and conflict. Typically these games consist of two or more competitive participants (agents) where the outcome of a participant's choice of action depends critically on the actions of others. When played iteratively participants can, through the adoption of strategies derived from the participant's model of their opponent, achieve improved payoff over time [1].

Robot-based movement rehabilitation can be considered an attempt to replicate the interaction between a patient and a competent physical therapist. For instance an experienced therapist will very quickly notice that a patient is making less effort to engage during periods of assistance by the therapist and in such cases they may give less assistance in order to coax more effort from the patient. This is an example of a strategy adoption by the therapist based on their experience of the patient's behaviour. In this work we advocate the use of such game theoretic principles in analysing these interactions with a view to designing suitable robotic controllers for automated therapeutic intervention in motor rehabilitation.

Through simple models of patient motivation and behaviour we can demonstrate plausible patterns of behaviour between patient-therapist. We start by defining each player's desires and objectives according to a basic mathematical formulation. We model the patient in this instance as a 'lazy' player who wants to complete each motor task but with the minimal effort possible. We model the therapist in this instance - a naïve robotic actuator - as a player who will always provide the additional assistance required to complete the task, $\boldsymbol{E_r = [E_n - E_o]}$, where $\mathbf{E_r}$ = Robot assistance (Robot effort), $\mathbf{E_n}$ = Effort needed, $\mathbf{E_o}$ = Effort offered (patient effort). The patient's playing strategy is then designed so as to offer less and less motor effort each turn so long as the task is cooperatively completed. We then model the interaction through a round based game.

Our preliminary model which is admittedly very basic demonstrates the concept of learned dependency in the simulation above. Given the rules as designed, it is clear that after several iterations the patient will offer almost no effort and yet still 'successfully' complete the rehabilitation task thanks to the additional effort offered by the 'over helpful' robot. We can experiment therefore with alternative robot behaviour so as to reduce the likelihood of this occurrence through basing the robot's behaviour on its experiences of previous patient effort.

Preliminary model simulation

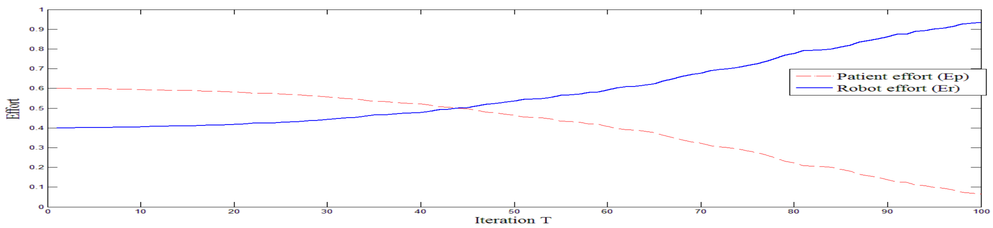

Fig 1.1: Simulation results showing learned dependency

Game Theory was developed to treat a wide class of dynamic interactions based on social decision making. From our preliminary models we feel it will have value in understanding the types of interactions that occur between patients and therapists. As an illustration of the approach we developed a simple model which demonstrates behavior which could be described as 'learned dependency', a known phenomenon observed in real patient-therapist interactions.

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Towards a Self-paced Brain-controlled Wheelchair using Shared and Automated Assistive Control

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An important aspect in EEG-based BCIs for wheelchair control is to offer a self-paced control strategy that requires minimum concentration time and minimum false detections, i.e., the user's intentions are continuously and accurately interpreted into control commands by the BCI. As yet, state-of-the-art BCI systems still generate false activations, which result in unwanted or misclassified control commands causing unreliability and safety issues for wheelchair control. One of the solutions to this problem, referred to as shared control, was proposed by Millan et al. [1] (MAIA). Using the shared control methodology, the control is shared between the computer and the user, i.e., the control is only handed over to the user if the BCI output crosses a certain confidence threshold.

Keeping in mind the limitations of the current day BCW strategies [1][2][3][4], this work describes two BCW interfaces; a self-paced BCW and a synchronous BCW.

In developing the proposed methods, the aim was to devise a methodology that can be used to assist the user as much as possible, and at the same time reduce the *cost* [5] in terms of concentration time and the mission time. Another objective was to devise a BCW strategy that could be used in unknown/new environments whether within buildings or outside. For this reason, both types of interfaces are investigated; the self-paced and the synchronous BCW and the *cost* 5 function is evaluated for each. The *cost* is evaluated in terms of the concentration time (the time the user has to concentrate to complete a task) and the mission time (the total time taken to complete a task).

The self-paced BCW uses a shared controller that regulates the angular velocities/orientation of the robot using the inputs from two main components: 1)BCI continuous classification output, and 2)Automated assistive component (AAC) that includes obstacle avoidance and corridor following algorithms. The purpose of this controller is to reduce the computational effort imparted by the user by using the AAC. Alternatively, the synchronous BCW takes the user input at predefined intervals in specific timeslots. The motor imagery is processed in specific time periods in a trial-based mode and a decision is taken based on the user's choice within these predefined timeslots.

These methodologies are compared to other BCW strategies [2][3][4][5][6] available in literature. The self-paced BCW strategy outperforms other motor imagery based BCW methodologies in terms of the *cost* function.

- **Acknowledgements**

This work has been supported by the UK-India Education and Research Initiative (UKIERI) grant 'Innovations in Intelligent Assistive Robotics'. Financial support was also obtained from InvestNI and the Northern Ireland Integrated Development Fund under the Centre of Excellence in Intelligent Systems project.

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Phase Segment Analysis Alleviates Contamination from Similar Frequency Targets in a 35 Target Phase Discriminating SSVEP BCI

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Recently brain-computer interfaces (BCI) utilising the steady state visual evoked potential paradigm have begun to employ previously unutilised phase information [1, 2]. Absolute phase response can be used to discriminate between targets that flash at identical frequency rates but are offset in phase of their alternation rate [3]. In traditional frequency tagged SSVEP BCI's SSVEP response need only to be distinguished from ongoing brain rhythms and background EEG. However in phase tagged BCI's, frequency similar targets are subject to contamination from not only ongoing brain rhythms but crucially the other non-attended targets that share alternation rates within the system. A main motivation for phase tagging is to increase the number of stable targets presentable on typical computer monitors that operate at a 60Hz refresh rate. Screen realty is typically limited in terms of physical size and resolution. Thus increasing the number of targets dictates reducing the size of individual targets or the separation between them, increasing the likelihood of cross contamination. This paper introduces a vector segmentation analysis method that operates on single cycle Fourier components to classify phase angle and compares this to a phase weighting/projection approach. The comparison is facilitated by an offline study with five subjects using a 35 phase tagged target system.

The ITR of the system using the segmentation approach is improved in all cases but particularly for lower frequency targets that have smaller inter-target phase spacing and are more populous in the system.

Stimuli flashing frequencies used were 6.66 Hz, 7.5 Hz, 8.57 Hz, 10 Hz and 12 Hz at every available phase offset (Table 1). Targets were arranged so that no similar frequency stimuli were situated adjacently. Five subjects completed ten sessions in total, five for calibration of phase responses where only one target was displayed at a time and five for testing whereby all targets were displayed. Each session consisted of 35 trials corresponding to attending every target in the system.

Table 1 Target alternation details

Frequency (Hz)	Max # of Phase Tagged Targets	InterTarget Phase Separation (degrees)
6.66	9	40
7.50	8	45
8.57	7	51.42
10	6	60
12	5	72

Table 2 Individual frequency and system performance (bold)

Projection		Segment Summation	
Accuracy (%)	ITR (bits/min)	Accuracy (%)	ITR (bits/min)
59	28.90	66	36.75
61	28.20	69	37.09
66	30.10	67	31.18
76	36.97	78	39.41
90	49.58	91	51.16
70.4	**65.92**	**74.2**	**71.83**

Projection method*:** Fourier coefficients for each frequency from a two second EEG epoch are projected onto each of the 35 stored phase calibration angles. The maximal value is selected as the attended target. ***Segment method: A two second EEG epoch is segmented into single cycle epochs for each frequency and each vector plotted independently. Vectors lying within constructed segments centered on the stored calibration phase angles with width corresponding to phase separation are vector averaged. The maximal value is selected as the intended target.

Accuracy's and ITR's are improved in all cases (Table 2) with the segmentation method likely due to contaminated vectors being omitted from classification.

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On the Selection of Dataset for Online Classifier Training

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Very little research has been done on selection of datasets for online brain computer interface (BCI) classifier training, especially participant concentration during data collection. This work presents a study, which highlights the importance of concentration by the participant to achieve good classification accuracies, by considering a simple oddball paradigm.

A four-class BCI oddball paradigm was designed, during which the participant perceived different colour flashes (red, blue, green and black in a randomized way) on white background. A flash of red, blue, green and black was considered a block. Flashtime was set to 100 ms, while ISI was set to 750 ms to prevent perceptual errors, as all participants were naive first time BCI users. Each participant was instructed to focus and keep a count of the cue (target) colour during the first two sessions (S1 and S2). The participant was asked to gaze/relax, thereby refraining from doing the task, during the third session (S3). To prevent habituation, the number of recorded blocks during each session was varied without the knowledge of participants. The number of blocks recorded during the three sessions was 36, 40 and 40 respectively.

Electroencephalogram (EEG) data were collected with a Biosemi ActiveTwo system at a sampling rate of 256 Hz and the experiments were approved by the University of Essex Ethical Committee. Eight optimum channels reported in [1], referenced to the average of mastoids channels were recorded. A forward-reverse band-pass filter with cut off frequencies (1 Hz and 12 Hz) was used to filter data from each channel, to obtain the signals in P300 spectral range, using Matlab commands: *ellip* and *filtfilt*. The designed filter lost no more than 1 dB in the pass band and had at least 40 dB attenuation in stopband. To remove eye-blinks and artifact activity, windsorising as described in [1] was implemented, due to its simplicity and effectiveness.

Two Bayes LDA classifiers with the same parameters as reported in [1] were trained using S1 session (participant concentrates) and S3 session (participant does not concentrate) datasets. The classification accuracies obtained when tested with S2 session are tabulated in Table 1. The results clearly indicate the poor classification accuracies obtained when a dataset where participant is not concentrating is selected for online classifier training.

TABLE 1: Classification accuracies (%) for various combinations of training and testing datasets.

Participant	S1-Training Dataset (Concentrating), S2-Testing Dataset (Concentrating)	S3-Training Dataset, (No Concentration) S2-Testing Data (Concentrating)
1	73.75	27.50
2	48.70	25.00
3	62.50	32.50
4	56.25	30.00

- **Conclusions**

This work justifies the fact that online classification performance of BCI systems depends entirely on the selected training dataset used to train a classifier. Hence it becomes imperative to monitor participant concentration for reliable accuracies. Our future work would therefore revolve around solving this issue by possibly integrating EEG-NIRS (Near Infrared Spectroscopy), to gauge participant concentration.

- **Acknowledgements**

CNG acknowledges support from Overseas Research and University of Essex Scholarships for this work.

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An intelligent Adaptive User Interface (iAUI) for enhancing the communication in a Brain-Computer Interface (BCI)

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Brain-computer interface (BCI) technology provides a means of communication that allows individuals with severe movement disability to communicate with external assistive devices using the electroencephalogram (EEG). But independent of any BCI related application/experiment, the command interpreted from the BCI user through an interface is a very important component in the system. The interface presented in this paper is designed such that it not only incorporates the requirement within the BCI application but also enhances the communication bandwidth of the system and gives complete independence with reference to the task selection.

An intelligent Adaptive User Interface (iAUI) has been designed and implemented practically by utilizing the information from the sonar sensors attached to the robot. The iAUI is composed of four main modules namely the communication module (CM), the information refresh module (IRM), the adaptable and adaptive module (AAM) and the monitor module (MM) (which is the front view of the iAUI) (cf. Figure 4). The iAUI communicates bi-directionally with the robot and the BCI user through the CM. The IRM updates the information about the surrounding environment (through the robot sonar sensors) and helps in the adaptation mechanism of the AAM. The IRM interacts with the AAM through the User Datagram Protocol (UDP). The AAM, in charge for retaining the existing rules or modifying the same, is responsible for the final adaptability at the MM. The adaptability of the MM refers to the process of modifying the front view of the user screen at the initiation of each new session i.e., once a command is issued by the BCI user or when a complete cycle of the interface is completed without the user issuing any command. This means that the commands which are offered to the BCI user (which as shown in Figure 4 are Backward, Forward, Left, Right, Halt and Main Interface) will adapt such that the most likely command is moved to the first place as the most probable choice so that the user can make the choice very quickly (cf. Figure 5) and thereby reduce the decision making time. The decision mechanism of the AAM is capable of triggering adaptations and hence it should be handled with utmost care. These adaptations solely depend upon the dynamic position of the robot with reference to the environment and this does not take into account the user characteristics or preferences. The adaptivity nature is applicable only during run-time and cannot be initiated by the interface components as they do not have any knowledge of the changing characteristics of the dynamic environment.
The iAUI has been practically implemented on the pioneer robot and the initial results are very encouraging.

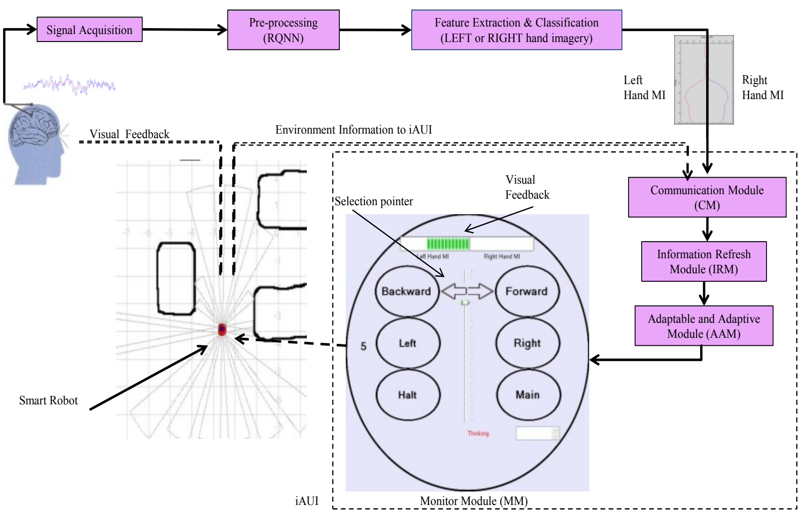

Figure 4. iAUI within the complete BCI system

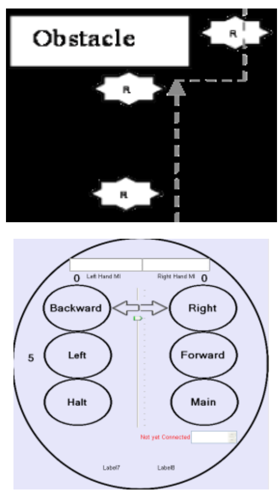

Figure 5: MM corresponding to position

Acknowledgement:
This work has been supported by UK – India Education and Research Initiative (UKIERI) grant on Innovations in Intelligent Assistive Robotics (SA-07-0074). Financial support was also obtained from InvestNI and the Northern Ireland Integrated Development Fund under the Centre of Excellence in Intelligent Systems Project.

A Low Cost Gaze- and Blink Based HCI

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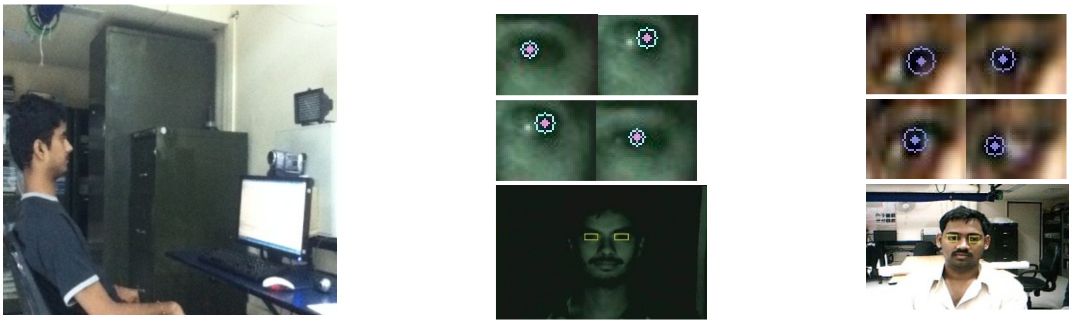
We implement a low cost human-computer interface (HCI) system which can be used by amputees and paralyzed persons, purely by eye actions such as blink and gaze control. Using this system, one gets the equivalent of simple mouse functionality, - point and click (both left and right click, including double clicks) – albeit at a rather low resolution. The system detects eye blinks of the user and can distinguish left and right blinks, which serve as left and right mouse clicks. For initialization, the subject just holds his/her head still for a few seconds: using involuntary blinks that would naturally occur during this time, the system both locates both the eyes [1] as well as forms online templates of the open and shut eyes of the specific user, valid for the rest of that session. The located eyes are tracked in real time using template matching and histogram back projection [2].

Reasonable amounts of head motion, carried out at reasonable speeds, are automatically detected and compensated. Automatic re-initialization of the system occurs if the user goes out of frame or excessively rapid head movement occurs. During operation, at all times, for both eyes, the status of the eyelid and the direction of the gaze (of only one of the eyes) are extracted on a frame-by-frame basis, and provided to the UI. The eye blinks of the user are detected in a robust manner by computing the Bhattacharyya distance between the histogram of the eye in the current capture and learned histograms of both open and closed eye templates; hence the system knows for each frame whether the eyes are open or closed, or in transition. When the eyes are detected as more than 70% open, the cornea tracker module is triggered. In order to detect the cornea, the eye image is subjected to contrast enhancement and colour filtering [3]. Gaussian smoothing and thresholding are performed upon the pre-processed eye image in order to eliminate the components that represent eye-lashes and eye-brows. The cornea is detected on the basis of colour and shape, and the Hough transform is used on the region to determine its centre and radius. Cornea detection is continuously repeated whenever the eye is open, so that it is continuously tracked. At the present stage of development, about 5 horizontal and 3 vertical corneal positions are being detected with acceptable accuracy. This controls cursor motion, and the left- and right blinks serve as the respective mouse clicks.

For capture, we use the visible band, assisted with a small amount of 850nm near IR. The ubiquitous colour webcam is sensitive up to about 1000nm, and only needs to be tweaked to move its IR filter. Existing ambient visible band light, supported by a few Near IR 850nm LEDs provide the required illumination for operation. The system is still under development, and awaits final parameter setting and integration.



(a) (b) (c)

Figure: (a) setup for IR band capture; (b) Some IR gaze tracks, with the last showing overall eye position for normalization; (c) the same as (b), but for visible band operation. In practice, both captures occur concurrently. IR illumination provides for higher detection accuracy, while remaining unobtrusive.

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A Virtual Keyboard with Multi Modal Access for people with disabilities

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Persons with speech and motor disorders face problems in expressing themselves in an easy and intelligible way. Computer based augmentative and alternate communication (AAC) systems are developed to assist these people. A Virtual Keyboard (VK), also called as On Screen Assistive Keyboard is a commonly used AAC system. A VK is characterized by the input modalities and the layout. An effort has been made to incorporate a number of input modalities and optimize the design layout to achieve optimum performance.

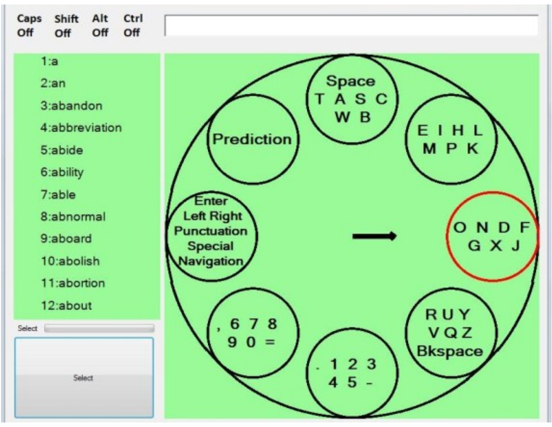

Figure 1(a) Virtual Keyboard: pointer pointing at the sub circle.

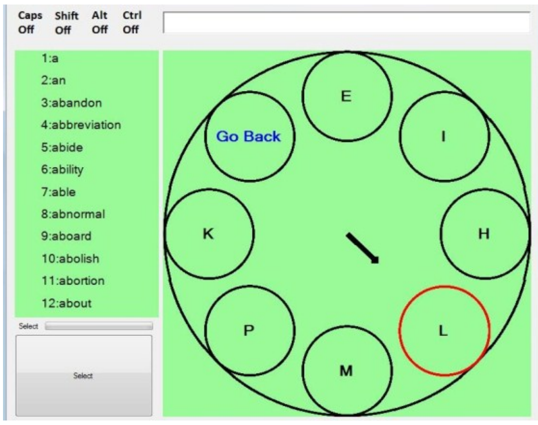

Figure 1(b) Expanded Sub Circle: pointer points at the character L.

Figure 1(a) shows the Virtual Keyboard. The pointer rotates and when it points to the desired sub circle, a trigger is used to select the sub circle which expands [figure 1(b)] and again the pointer starts to rotate. As the pointer points to the desired character a trigger is used to select it and it is typed in to the corresponding application.

Three different technologies have been incorporated to be used as an input. The Brain Computer Interfacing (BCI) based on EEG uses 'vivid imagination' of a motor activity as a trigger. The Eye Tracker technology uses prolonged gaze and/or eye blink as a trigger while access switches (also called as soft switches) use any active body part such as hand, foot, mouth or head as a trigger. Any one or the combination of these can be used as inputs. The grouping of the characters in sub circles as well as positioning of the characters in the sub-circles has been optimized using two criteria namely the frequency of occurrence of alphabet in the English text[1][2] and the probability of the alphabet being the first letter of the word[3]. Due to non availability of subjects with speech and motor disorder, user trials were carried out with healthy individuals only. The results obtained were analyzed on various parameters such as typing duration, and errors committed. The analysis found that in case of sequential alphabetical layout, for typing a character, average number of activities (including the waiting time for pointer to rotate and triggering mechanism to select a character) required is computed to be 6.47 while for the proposed layout, the average number of activities drops down to 4.55, establishing the superiority of the design against other alphabetical layout VK [4].

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Accurate Link Selection for Web Browsing using Eye Tracker

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Introduction: With recent technological advancements, eye trackers, i.e. devices able to detect the user's gaze and direction on a screen, have been greatly improved [1]. But using gaze as an input lacks the accuracy needed to select small targets [2] on a GUI firstly due to the nature of eye movements and secondly because of the way in which we use our eyes in conjunction with other motor actions. In this work we address the problem of link selection while surfing the web using a head mounted Arrington Research Viewpoint eye tracker using a proxy web browsing system. Eye tracking systems continue to cause problems for the disabled users due to their inaccuracy to pinpoint small target areas. So we introduced the system of mapping the links on a webpage to an enlarged virtual keypad by assigning unique numeric identifiers to represent each link. The user has to select the unique numbers displayed on virtual keypad which will be activated by selecting the select button on the top of the web page. The system then directs the user to the target embedded in that link. The virtual keypad pops up and spans across whole monitor screen thus allowing an easy and accurate selection of the desired link as shown in Figs. 1 and 2. Then user can select the numbers of his choice if s/he gazes at the buttons for about 2.5 seconds which is called as 'dwell time.'

Fig. 1 Select button for popping out virtual number pad.

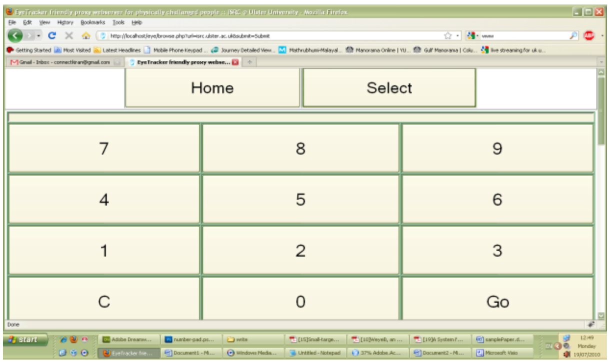

Fig. 2 Popped out virtual number pad.

System Design and Evaluation: The HTML and PHP based Client URL (CURL) Library [3] are used to develop the frontend and backend respectively. We use XPath to extract all the links and link labels from the fetched webpage. These link labels are then modified and unique identifiers are concatenated to the end of the link labels. The virtual number pad is coded in JavaScript which contains ten clickable buttons. We carried out formal experiments simulating real life scenarios on a PC running Windows XP. Eight novice unpaid volunteers from the ISRC participated in the study. They were seated about 60 cm from the display without a head-rest. The participants were asked to perform three tasks: (T1) Navigate to any link in the top menu. (T2) Navigate to any link in the left navigation menu. (T3) Navigate to any of link on the right side of the website. Each task was performed three times. Table 1 shows the results: 'y' means that at least two trials out of three were successful, while 'n' indicates the other case.

Table 1: Text Results

	Users							
	U1	U2	U3	U4	U5	U6	U7	U8
T1	y	y	y	y	n	y	y	n
T2	y	y	y	y	y	y	y	y
T3	n	y	y	y	y	n	y	y

Conclusion: Compared to other eye-controlled web browsing systems, the presented system differs in the following ways: (1) The user does not need any additional software to be installed. (2) It doesn't depend on the operating system. (3) It will work with any eye tracker (4) It can be implemented as a proxy website enabling access using any web browser. As for future work, it is planned to integrate an eye typing system to enter the web address and also an efficient page scrolling method.

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On Approaches to Hardware Design of Mobile Robot Platforms

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Abstract
While Indian researchers started taking interest in robotics way back in 80's, most of the efforts were put in developing algorithms for solving various dynamic/kinematic problems of the manipulators and mobile robots. Most of these algorithms were demonstrated on the robot platforms acquired from abroad. With the advancement in embedded system technology in the country, it looks feasible to develop our own robots which can cater to the requirement of researchers in the country. With this motivation, the author is working on a project where he is developing some mobile robot platforms which can be used for several applications. This paper is about his work in this direction.

Introduction
Our work primarily involves development of mobile robot platforms which can be used for various applications including assistive robotics. We are inspired by the work by various authors [1,2,3] in this field. We are currently developing robot platforms based on low-power single board computers like Beagle or Pandaboard, Vortex86DX based RoBoard and the atom processor based boards. The advantages of these boards is that the whole robot can be powered using 6-12V battery supply. We are adopting three architectures for our robots – one where we use Arduino boards for data acquisition from sensors and motor control and Beagle board for higher-level tasks like image processing; in the second architecture, we control the whole robot using a single board computer that already has on-board I/O and PWM pins. This makes whole design even more compact; Finally, in the third architecture, we intend to use Intel's Atom-based standard mother boards for controlling motors and collecting information from various sensors. All these robots make use of GNU/Linux as the operating system and hence our development is based on open-source softwares.

Projects

Currently, we are working on the following four projects:

1. Mobile robot platform development for Swarm Application
2. Biped-Robot Development
3. Quad-copter Development
4. A Robotic Wheel Chair

Acknowledgements

This project is funded by Ministry of Human Resource Development (MHRD), Govt. of India under the auspices of "National Mission on Education through Information, Communication and Technology (NMEICT)". The details of the project is available at http://www.themachine.in.

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Multi-Agent Formation Control using Artificial Potential Field and Adaptive Fuzzy Sliding Mode Control

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In the present work, a decentralized control strategy is designed for self-organizing swarm systems based on the artificial potential functions (APFs) together with sliding mode control (SMC). The path planning of the agents are done using artificial potential function method [1] [2] and a sliding mode controller is designed such that the velocity of the agents is enforced along the negative gradient of the potential function. A fuzzy logic inference mechanism is utilized for implementing a fuzzy reaching control law [3] [4] to remove completely the chattering phenomenon in the conventional SMC. In addition, to confront the uncertainties existing in the dynamic model of the agents, an adaptive algorithm, which is derived using Lyapunov stability theory, is utilized to adjust the fuzzy parameter for further assuring the robust control performance. The simulation studies are performed in order to illustrate the robustness of the adaptive fuzzy sliding mode technique. In the present case, six agents with point mass dynamics and additive sinusoidal disturbance are considered.

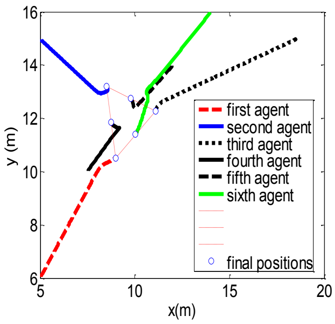

Fig. 1: Path of the agents forming a triangular formation.

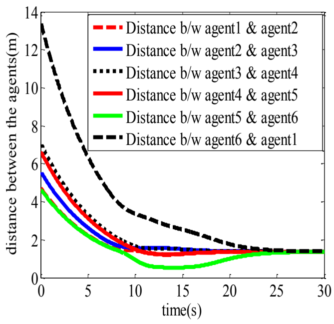

Fig. 2: Distance separation between the agents in formation.

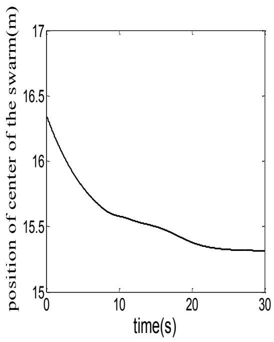

Fig. 3: Position of the center of the swarm

Fig.1 shows the paths of the agents, which are required to form an equilateral triangle in $\Re^2$, with three agents at the corners of the triangle and three at the middle point of the vertices. The initial positions are chosen randomly and the initial velocities are taken as zero. It is found that all the swarm members move towards each other and form the required cluster within 30 seconds, maintaining a separation distance of 1.37m as shown in Fig.2. From Fig.3, it is clear that once all the agents reach their sliding manifolds, the center of the swarm become stationary. The fuzzy sliding mode control system, in which fuzzy reaching control law is embedded into the conventional SMC system, is found to be capable of removing the control chattering. Hence the center of the swarm becomes stationary. The algorithm can be extended with some cluttered environment after incorporating an obstacle avoidance scheme. The present scheme can be implemented in the case of swarm of robots employed for various tasks.

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A novel vision based approach of human tracking with the mobile robotic wheel chair

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This paper presents a novel and robust approach to detect and follow a human with a mobile robotic wheel chair. This work is important as the patient sitting in the wheel chair should be able to follow a human assistant in many daily life situations. In order to follow a human, both the initial detection of human and the subsequent tracking need to be implemented. As the robot is initially static, initial human detection is done using a background subtraction (BS) technique [1]. BS techniques are sensitive to the shadow of the object. For removing the shadow from the foreground detection, a RGB-based shadow removal method has been developed. To remove the outliers' objects, filters are formulated based on the aspect ratio and horizontal projection histogram (HPH) of the human [2]. The HPH of a human in upright position always has a pronounced valley, corresponding to the head and the torso junction, and can be located at a height 0.1 to 0.25 times that of blob from the above. Once a foreground blob which represent a human, is obtained, segmentation is done along the pronounced valleys in the HPH as described in [3]. After segmentation, the color distribution of the torso and the legs are learnt individually, by taking an *N*-bin histogram of hue from the HSV color space. Human detection in subsequent frames is done by back-projecting the color histograms of the human torso and legs. The vertical projection histogram (VPH) of a human silhouette has a unique "bimodal-with-narrow-valley" pattern when the two legs of the human are apart. To make the human detection robust, a shape analysis algorithm is developed to find the "two legs apart pattern" in the VPH of the detected foreground. For tracking, linear motion controllers are proposed: these require visual information to generate motion commands for the robot.

- **Results**

Figure 1, demonstrate the workability of the human detection algorithm. Fig. 1(a) shows the background image when the robot is static. Fig. 1(b) shows the image containing the foreground object. The binary motion image (BMI) 1(c) after the background subtraction detects the presence of the foreground object. But the human detection algorithm decides this foreground blob is a non-human object. The Fig. 1(d), shows a image containing two objects: one human and the other not. Its BMI 1(e) detects both the foreground objects. The human detection algorithm identifies the blob corresponding to the human as human and rejects the others 1(f).

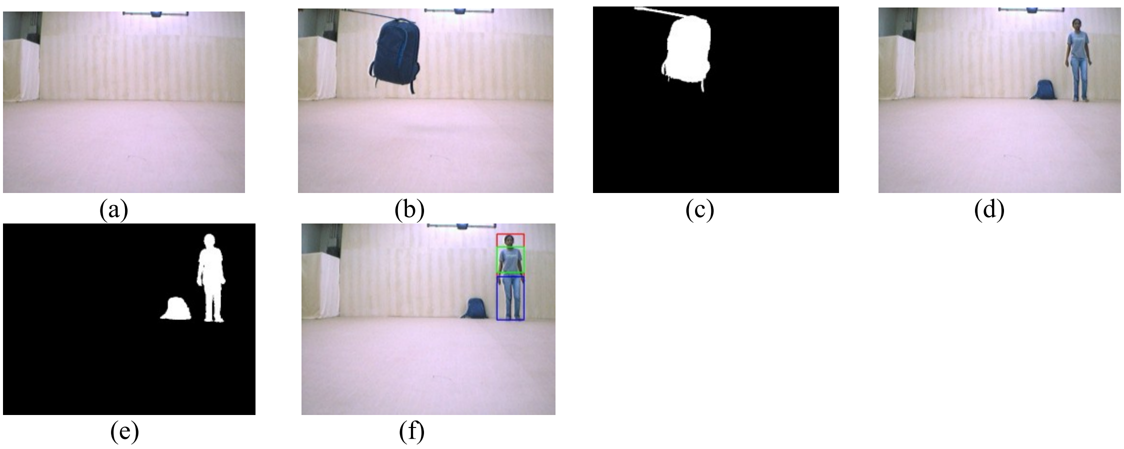

Figure 1. Experimental results of automatic human detection

- **Acknowledgements**

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Adaptive Critic based Redundancy Resolution scheme for Vision based Robot Manipulation

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Robot has been increasingly deployed in real world for assisting the human beings in their daily life. Real world challenges necessitate the use of redundant manipulators controlled with visual feedback for better maneuverability and to identify the environmental challenges. Visually controlled manipulators can assist the human beings in every activity with their dynamic visual feedback. The control of a redundant manipulator is challenging task since the inverse kinematics of the redundant manipulator is one-to-many relationship. Though visual feedback gives dynamic information about the environment, sensor noise, model inaccuracies and the unknown environment depth information further increase the complexity of vision based manipulator control. The dynamics in the real world environment necessitates the development of a control architecture which is robust to the environmental changes. An adaptive control scheme which can adapt and improve the control performance with the environmental changes is imperative for real life application of the manipulator.

This paper discusses about an adaptive critic based real-time redundancy resolution scheme for the kinematic control of a redundant manipulator. Adaptive critic has been used in many industries to achieve near-optimal control in real-time through learning. It has not been studied for the kinematic control of the manipulator since the approach is not direct. In this research, the kinematic control of the redundant manipulator is formulated as a discrete-time input affine system and then an optimal real-time redundancy resolution scheme is achieved with adaptive critic based approach. The desired additional task is defined as an integral cost function and then global optimal controller is achieved through learning using critic framework. The near-optimal costate dynamics is learned through a Takagi-Sugeno fuzzy based network and the learned network is used to control the redundant manipulator as shown Fig 1. With adaptive critic based optimal control scheme, the optimal redundancy resolution is achieved in real-time without the computation of inverse which makes the method computationally efficient.

- **Results**

The paper focuses on the redundancy resolution scheme developed with single network adaptive critic (SNAC) where the primary positioning task and the desired additional task is modeled as an integral quadratic cost function. The SNAC based redundancy scheme has been tested on a 7 degree of freedom redundant manipulator for minimum norm movement and kinematic limit avoidance. The robot configurations at various operating points while following an elliptical trajectory are shown in Figs 2 and 3. The minimum norm which results in smooth joint trajectory is shown in Fig 2. An additional kinematic constraint of (-1.25, 1.25) radian is applied on the 4th joint of the manipulator, and the robot configuration learned with the learned critic network are shown in Fig 3.

Fig 1. Critic based Redundancy Resolution

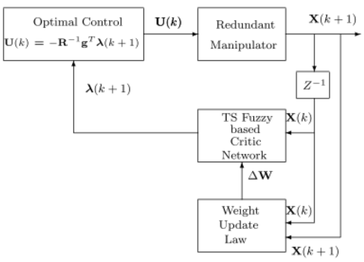
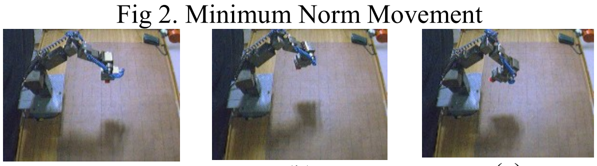
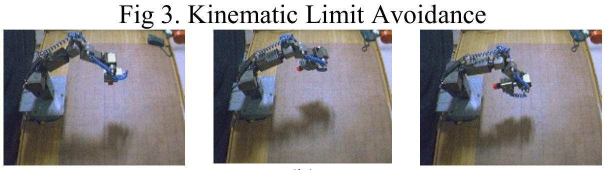


Fig 2. Minimum Norm Movement



(a) (b) (c)

Fig 3. Kinematic Limit Avoidance



(a) (b) (c)

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Learning to Control Robotic Systems

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Robots are active agents which can be programmed to exhibit human-like behaviour. These agents can learn from experience. In this work, various learning based approaches to visual servoing will be discussed. ***The Visual servo problem is to coordinate joint positions of the arm through velocity actuation such that the actual visual featurses converg to desired visual features.*** Online estimation of image Jacobian and accurate modeling of the kinematic Jacobian are two necessary components in designing an effective visual servo-control [1]. Since the manipulator under consideration is of seven degrees of freedom, the redundancy involved provides the controller with multiple choices to actuate a control action given a dynamic situation. We have developed many learning strategies by which inverse kinematics can be learned on line as well as the redundancy can be resolved through optimization of instantaneous and global cost functions.

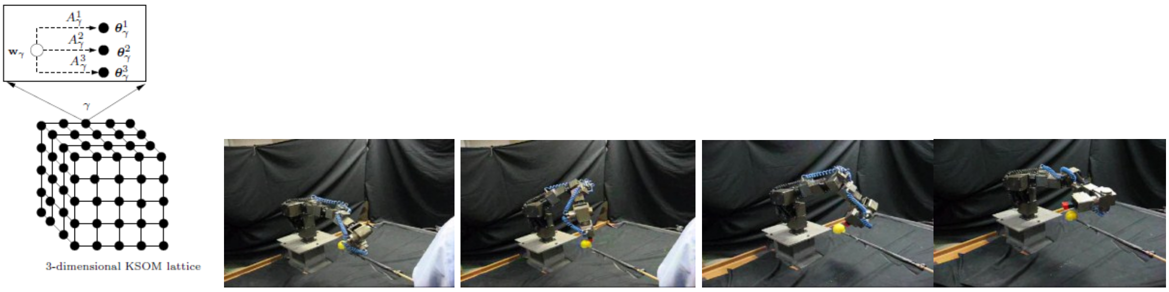
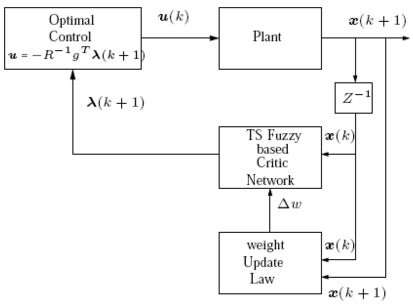


Fig. 1: Self-organizing KSOM Network that preserves the redundancy

As shown in Figure 1, a redundancy preserving network using KSOM has been developed so that the manipulator is able to reach the same target in different kinematic configurations - each configuration is a result of the optimization of a specific cost function. Details of this concept can be found in [2-3]. The same concept has been extended with a network architecture that optimally predicts a control action through network inversion using a hint generator as described in [4].



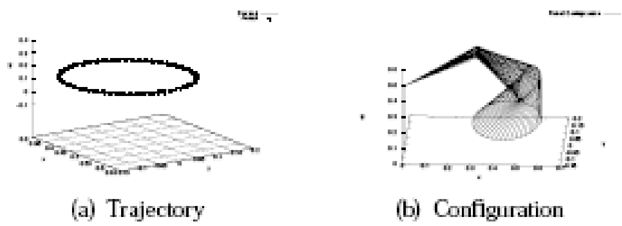


Fig. 2: Adaptive Critic Network for Visual Servoing Fig. 3: Trajectory Tracking and Kinematic Configuration

The optimal redundancy resolution using an integral cost function has been achieved using a single network adaptive critic [5] where the manipulator kinematics have been expressed as an input-affine discrete-time nonlinear system. Figure 2 shows the structure of the adaptive critic and the corresponding trajectory tracking and the associated kinematic configurations are shown in Figure 3. The author will demonstrate many such learning strategies by which a robotic system can be effectively controlled. Convergence of learning algorithms as well as the stability of the control system are guaranteed while developing such learning control strategies.

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Design of an optimal finger exoskeleton and its control based on human hand motion data

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Human finger motion for performing various tasks of daily living is quite complex, as it involves interaction between multiple degrees of freedom. In order to design and control optimal finger exoskeletons we need to analyze the cooperation existing between different fingers and also develop efficient human hand inverse kinematics algorithms for control. This presentation will first discuss the cooperation existing between different fingers of the hand and then explain the design of an optimal exoskeleton using 4-bar mechanisms for rehabilitation. Based on the human motion data obtained through a 3D motion capture system, an efficient inverse kinematics algorithm was developed to control the exoskeleton, based only on the fingertip position. The exoskeleton is capable of being controlled using EMG as well as inverse kinematics based models.

The cooperative behavior of the thumb, index and middle fingers during a simple rotation task was analyzed, based on the three criteria of (i) manipulability measure, (ii) major axis direction angle of the manipulability ellipsoid and (iii) ratio of ellipsoid axis lengths. Thirty healthy subjects volunteered for the study. A three dimensional motion capture system was used with 15 markers attached to the joints of the thumb, index and middle finger. Subjects rotated a small object across the extended, intermediate and flexed finger planes and the respective positions of the markers were captured. The finger joint angles during motion were obtained from the position vectors of each marker. Post analysis, it was observed that the thumb and middle finger may be active, while the index finger may operate passively as a support for rotation, when manipulating small objects.

As the human finger joints cannot be modeled by single revolute joints due to the instantaneously changing joint centers, four-bar mechanisms have been designed to move each joint of the exoskeleton. Each four-bar mechanism is optimized using genetic algorithms, by minimizing the tracking error between the coupler of a four-bar and the human finger link trajectories [1, 2]. It is observed that the designed 4-bars can accurately track the motion of the human fingers. The exoskeleton was controlled by using the EMG signals obtained from the subject's forearm muscles. The nonlinear mapping between the EMG and finger motion was learned using a back propagation trained feed forward neural network. An efficient inverse kinematics algorithm was also developed by performing instantaneous manipulability measure optimization of the finger joint angles, based only on the finger tip position. This control method best emulates human finger motion.

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Advancing Motor Imagery based BCI and its Applications

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The motor imagery (MI) based BCI uses cortical activations resulting from MI tasks to create a direct communication link between human brain and computing devices. Its major advantage is that it can facilitate a self-paced natural communication channel between the user and assistive systems as well as has potential to support motor recovery in post-stroke paralysis. However, several factors such as non-stationary brainwaves, and time-varying electrode characteristics and mental states, may degrade its performance significantly [1]. Additionally, some subjects are not so good in performing MI, categorised as having BCI aphasia but do improve with practice. Also, in motor recovery applications, initial moderate performance of novice stroke sufferers may cause frustration and impede recovery. To account for these performance degrading effects, recently we have undertaken investigations in primarily in three main areas: signal processing, multi-sensor integration, and applications involving brain-actuated wheelchair/mobile robot control and BCI-supported stroke rehabilitation.

Signal processing and multi-sensor integration

As a result of non-linear dynamics, EEG signal distribution is known to be non-Gaussian during motor imagery. A higher order statistics, the bispectrum, should theoretically be zero for Gaussian distribution and non-zero only if the distribution is non-Gaussian. The bispectrum method has been used to extract features of nonlinear interactions over several frequency components from MI-related EEG signals. A BCI designed using the bispectrum features along with an LDA classifier [2] has been found to provide enhanced feature separability and robustness against noise. Simultaneous recording of EEG and ECG signals were made while six healthy subjects performed effortful MI tasks. A hybrid BCI designed by integrating features extracted from both EEG and ECG [3], provided significant enhancement in performance compared to the case when either of the features were used alone.

Applications

An MI BCI has been applied for providing neurofeedback to five chronic hemiplegic stroke sufferers undertaking MI practices as part of a rehabilitation protocol involving both MI and physical practices of a rehabilitation task of 30 minutes duration each [1]. All five patients achieved improvement in at least one of the two rehabilitation outcomes, Action Research Arm Test (ARAT) and grip strength (GS) and these two were found sufficient to monitor incremental functional gains during the intervention for all patients. The improvements approached a minimal clinically important difference (MCID) for the ARAT. However the task classification accuracy (CA) rate improvements obtained with 11 to 12 sessions of practice over a six week period, were not statistically significant. Nevertheless, the cortical activations in terms of event related de-synchronisation/synchronisation (ERD/ERS) were found to be correlated with changes in rehabilitation outcomes. However, for only two participants, the ERD change was statistically significant between the first and the last session. It was felt that for significant enhancement in CA rates, the study should run much longer, i.e. at least 20 or more sessions. Overall, however, the crucial observation is the fact that the moderate BCI classification performance did not impede the positive rehabilitation trends. Therefore the study concluded that the BCI supported MI practice is a feasible intervention.

Challenges and Way Forward

Human beings use multiple mediums for communication, e.g. speech, hand gesture, changes in face and voice level. Multiple brain areas are involved in processing any perception-action [1]. Enhanced performance through multi-modal and distributed hybrid BCI design, unsupervised adaptation, better brain modelling, and robust decoder design, environment monitoring, and intelligent electrode assembly, may go a long way in making the MI BCI more practical. Systems need to be designed so that even with lower accuracy, its use is practical, e.g. BCI may act only at the executive level and delegate the task. In terms of motor recovery, further work and extensive controlled trials are required to be undertaken to ascertain most appropriate content, dose and frequency of MI/physical practices. Also there is a need to investigate whether MI/physical practices through imitation learning in a team can provide enhanced recovery. Mental state monitoring maybe needed to assess the fatigue and accordingly decide appropriate exercise doses.

Acknowledgements
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Hierarchical Skill Building

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A close look at the literature in robotics will reveal that robots, developed either in universities or in private companies, are provided with an increasing set of skills. Most of these skills are coded in programs or routines freely available to researchers and engineers alike, so that they can build more sophisticated systems. However, in spite of the huge array of skills available to a robot, autonomous machines still struggle to have a real impact on our life. Among other reasons, we believe this is due to the difficulty of creating a complex system even when it is made of already available parts. Even if a single skill is based on a well-known and reliable technology, there are little or no tests of the same skill when it has to cooperate and coordinate with other skills. Most of the time even this reliability can not be proven, as the robot is supposed to operate in a world where huge amount of information comes from noisy and deceptive sensors. This picture lead to nowadays' impression that huge leaps are made every day in research laboratories but only small steps are made in industry. These problems are well know in the robotics community, and researchers are trying to address them by allowing a robot to learn a skill instead of having it pre-programmed. Some approaches that have been successfully applied to robotics are Reinforcement Learning (RL) [1], Evolutionary Algorithms (EA) [2] and Artificial Neural Networks (ANN)[3]. Learning skills is a very appealing option, as it will solve most of the above problems: whenever the robot does not know how to solve a problem it learns (even by trial and error) a new skill that will meet the new requirements. Learning however is plagued by some inherent difficulties:

- Practically none of the proposed approaches scale well with the difficulty of a problem. The harder the problem the robot has to solve, the longer it will require for a learning algorithm to converge to a satisfactory solution.
- Avoiding local minima and sub-optimal solutions is still an unsolved problem.
- An already learned skill is hard to update without impairing some other functions. This is known in literature as "Catastrophic Forgetting".

These problems slowed the proliferation of learning robots, so that very often a robot is only able to learn skills that are programmable with the same or less effort. Another obstacle to overcome is how to integrate several skills so that they can all contribute to build a complex robot behaviour. Several robotic architectures were born during the last decade to combine basic behaviours into more complex ones that involved perception, planning and action [Ark98]. However the design of a proper architecture, orchestrating several concurrent behaviours, is difficult for many real-world applications.

To address the above problems, we propose an evolutionary algorithm that allows a robot to autonomously build new skills by combining old ones. These old skills could be pre-programmed, learned or they could be a composition of other skills. The latter case is of particular interest, as it induces an hierarchical organisation of skills. This particular structure is known to facilitate abstraction and learning [4]. Together with recombining old skills, our approach allows a robot to learn new skills in the same context as learning to combing old ones.

A structure that is expressive and general enough to describe a solution to a problem is Finite State Automaton (FSA). Every node in a FSA represents a skill, which in turn, given the hierarchical structure, can be a FSA on its own. Learning a solution to a problem by reusing old skills means learning a FSA whose ending state corresponds to the wanted solution. We therefore developed a new evolutionary algorithm to find FSA that provide a suitable solution to a given problem either by combining pre-existent skills or by creating new ones.

We present experimental results that prove that our approach is suitable to generate new robotic skills both in simulation and on the real robot. Our proposed approach has been applied in three scenarios:

1. A robot that learns to move around a table to find the best grasping position for an object.
2. A robot that learns to pour water.
3. A robot that learns to stack objects independently from their initial position.

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Stable Coordinated Platooning by a Group of Mobile Robots

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Abstract
In this work, a platooning control of a group of mobile robots is proposed. The proposed method ensures self-collision free coordination and maintenance of the group under different navigational situations. The robots decide and adjust their velocities as per the motion initiatives of the front leader. Furthermore, the front members keep their relative headings with respect to the leader. The proposed method is experimentally verified using a group of Pioneer P3-Dx mobile robots. The results show satisfactory performance.

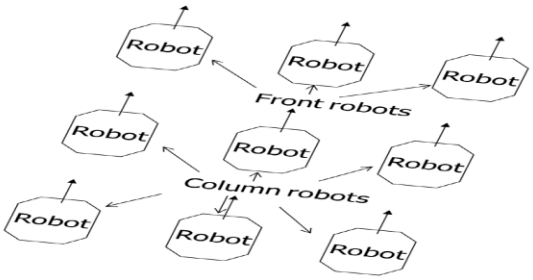

Fig. 1: Platoon: front and column robots

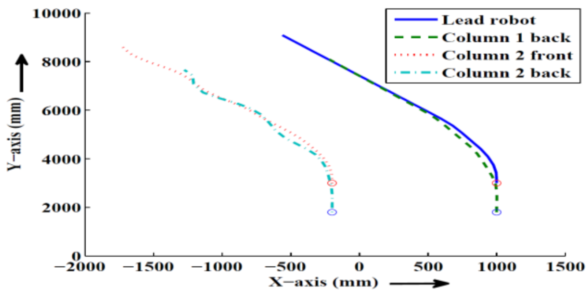

Fig. 2. Formation resuming straight movement after consecutive left turns

Formations of robots have various applications ranging from satellite formation, wide area surveillance, military applications. Members in a formation can be controlled by centralized method [1] or decentralized method [2], [3], [4]. In [5], Ray et al. proposed decentralized formation coordination schemes. In this work, we are interested in a multi-robot formation which navigates as a platoon (Fig. 1). The main objective of this research is to develop control algorithms under various space-time bound constraints for a stable formation. We tested the proposed method under various navigational conditions (case 1 through case 5) for a platoon of two rows and two columns. The members of the platoon follow the motion patterns of the leader while maintaining safe separation distances among each other (Fig. 2). Furthermore, the front members keep their relative headings with respect to the leader (Fig. 2). The rms errors in separation distances among the members are shown in Table I. The rms errors in maintaining the relative headings for these cases are shown in the Table II. In all the experiments, it is observed that each member is capable of adjusting to the changes adopted by the leader.

Table I: RMS errors in the separation distances (mm)

Case	Front members	Column1 members	Column2 members
1	2.7908	59.4311	114.2973
2	55.8127	166.0911	100.5728
3	35.3212	78.0201	57.7486
4	28.7420	37.6571	91.0993
5	37.7447	77.5572	72.4114

Table II: RMS errors in the relative heading

Case	Error (degree)
1	2.7774
2	2.6401
3	3.8233
4	4.4841
5	2.4923

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Empirical Mode Decomposition vs Standard Band Power Features for a Brain-Computer Interface

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A number of studies have shown the potential for applying Empirical Mode Decomposition (EMD) for mu rhythm desynchronisation detection and feature extraction in a motor imagery based brain computer interface (BCI) [1]-[4]. Bandpower (BP) has been a commonly used feature for discriminating motor imagery in a BCI however these EMD studies do not show the comparative performance against BP for feature extraction. This extended abstract presents an analysis of EMD compared against standard feature extraction using BP with standard frequency band (8-26Hz). Results show feature extraction using EMD provides over 6% mean improvement in classification accuracy (CA) across nine subjects compared against band power CA.

EMD is a data driven time-frequency technique which adaptively decomposes a signal by means of a process called the sifting algorithm, into a finite set of AM/FM modulated components, referred to as intrinsic mode functions (IMFs) [5]. IMFs represent the oscillation modes embedded in the data. The EMD algorithm decomposes the signal into IMFs where the extracted components satisfy the so-called monocomponent criteria, and the Hilbert transform can be applied to each IMF separately to obtain the phase information [5].

The EEG data used was recorded whilst subjects performed motor imagery where they imagined moving their left and right hand/arm. Signals were recorded from three channels positioned at C3, C4 and Cz according to the international 10/20 system. The EEG data was sampled at 125Hz and bandpass filtered using a butterworth filter between 8 and 26Hz. Each run of recorded data involved recording a total of 120 trials of 7s duration with the cue stimulus appearing at t=3s. The data were provided for the BCI competition [6].

The processing involved windowing the data provided for each subject using a 1-sec window. 5-fold cross-validation was used in both BP and EMD, together with Linear Discriminant Analysis (LDA) as a classifier. The window that provided the peak accuracy using standard log of the variance of BP was used to compare the EMD. Using EMD, at least four IMFs were extracted for each channel using the selected window position (sometimes more than four IMFs were extracted; for consistency we used the first four in each case). After extracting the IMFs, the Hilbert-Huang spectrum was computed using the Hilbert transform [7], from which the instantaneous frequency and amplitude were extracted and used to find the Marginal Hilbert Spectrum. From this set of data, variance, root-mean squared and kurtosis was we calculated as features from the amplitude and frequency components, providing a total of 6 features per channel.

The maximum classification accuracy was found to occur between t=4.4 and t=5.2 for all subjects. Average classification accuracies for each subject for both BP and EMD are illustrated in table 1. The results strongly indicate that EMD is better than standard BP (i.e., no subject specific frequency band chosen). The difference between the two methods is significant ($p<<0.001$) based on repeated measures analysis of variance analysis (RMANOVA). The results suggest that EMD has potential for application in a BCI. Future work will involve exploring additional feature extraction method to employ in conjunction with EMD and a suitable feature selection method the optimal subset of IMF derived features.

Table 1: Classification Accuracies for BP and EMD for nine subjects

Subject	BP	EMD
1	63.59	77.08
2	65.27	70.83
3	68.21	72.92
4	92.81	96.15
5	66.97	75
6	70.34	75
7	65.29	70.83
8	63.53	69.64
9	67.86	72.92
Mean	**69.3189**	**75.5967**

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